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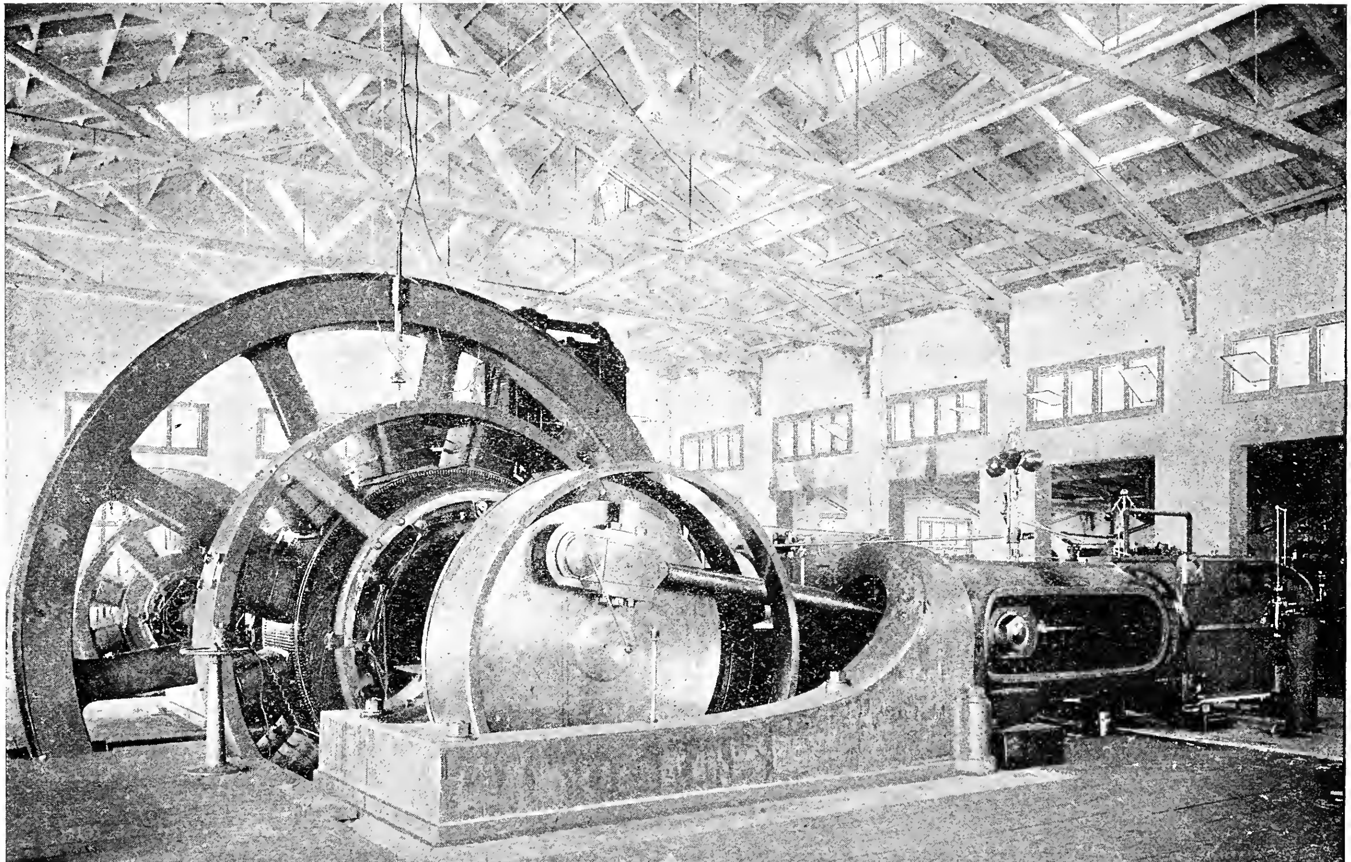

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[*Frontispiece.*]

STATIONARY

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SIMPLE AND COMPOUND;

ESPECIALLY AS ADAPTED TO

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By ROBERT H. THURSTON, A.M., LL.D., DR.ENG'G,

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SIXTH EDITION.

REVISED WITH ADDITIONS.

FIRST THOUSAND.

NEW YORK:
JOHN WILEY & SONS.
LONDON: CHAPMAN & HALL, LIMITED.
1899.

PREFACE TO THE FOURTH EDITION.

THIS little book is composed of articles written by the author for the *Electrical Engineer*, supplemented by later revision, and by the addition of matter relating to the new multiple-cylinder engine, which had been originally prepared for the lecture-room and subsequently presented in abstract to the American Society of Mechanical Engineers. It had its origin in a request, by the editor of the periodical above mentioned, that the readers of that journal be given an account, in simple and concise but fairly complete form, of the various types of steam-engine in common use; of the principles of their design; the circumstances determining their efficiencies and their economy of steam and fuel; their various forms as usually built, and the best methods of insuring further improvement.

In complying with this demand, it has been thought advisable to give a brief outline of the progress of discovery and invention, from the earliest days of application of steam to the production and utilization of mechanical energy; to trace the steps which led up from the rude devices of Savery and Newcomen to the highest attainments of the engineer of to-day; next, to exhibit the principles of

economy in the efficient application, through the operation of the steam-engine, of heat-energy into mechanical power, by conversion of the one form of energy into the other, observing the causes and methods of waste and the means available for their reduction, if not for their extinction, in some directions ; and finally, to describe and illustrate the standard types of engine to-day in use, and the details, so far as may seem important, of their construction.

The peculiar demands made upon the designing and constructing engineer in later years by the introduction of electric lighting, with its requirements of economical operation of machinery having very high speed of rotation and absolutely compelling exact regulation, has led to the invention of new forms of engine, and especially of new methods of steam distribution and regulation. This has resulted in the introduction, in turn, of a new class of engines, known to the profession and in the trade as "high-speed engines," which possess these essential qualifications of great velocity of rotation, and of nicety of regulation in a superlative degree, and which have, by their sharp competition with the older types, in their turn compelled an unexampled improvement in the latter, in the endeavor, largely successful, to adapt them to the same purpose. Thus high speed, very perfect regulation and very smooth action at maximum speeds, have come to characterize the steam-engine of the present time in far greater degree than ever before ; while modern systems of manufacture and the extensive application of special tools, designed each for its special work, have reduced costs of production of this right arm of civilization to such an extent

as to insure a more rapid progress in the useful arts than has ever yet been seen.

This subject was deemed so important to the mechanical engineer and to all having anything to do with the remarkable expansion now occurring in the work of electric lighting, and of the extension of the systems of application of power, through the use of electricity to the impulsion of street railway cars and to the machinery of the smaller industries (to the supply of power to small shops and establishments), that it was considered probable that a philosophical account of the rise and progress of this now enormous industry of steam-engine construction, and especially of its product, would be likely to prove acceptable to many intelligent readers outside as well as within the profession. In this anticipation the publishers have not been disappointed, as the fact of the sale of rapidly succeeding editions proves to their satisfaction as well as to that of the author.

The latest addition to this little work is in a final chapter on the multiple engine and the principles of its design, construction, and operation in successful competition with the older forms. The importance of this new departure in the construction of small engines, for electric lighting and similar purposes, may be imagined when it is noted that in some cases, at least, the compounding of a well-known type of "high-speed" engine has reduced its consumption of fuel for similar sizes and work enormously, the simple using almost double the amount of steam and fuel, in the smaller sizes, demanded by the compounded engine of otherwise exactly similar design and construction. As is

stated in the text, the smaller the engine the greater is the original waste, the greater the margin for improvement, and the greater the gain to be anticipated by this change.

The author has endeavored to do full justice to the various engines described, while carefully avoiding the expression of merely personal opinion in reference to debatable points.

For a more complete history of the development of the modern forms of steam engine, as well as for an account in considerable detail of their various construction, and for discussions of the scientific principles and the practice in steam engineering, the reader is referred to the larger works of the author: his Manuals of the Steam Engine, of the Steam Boiler, and of Engine and Boiler Trials. This little book is intended to present the briefest possible summary of the subject in popular form.

PREFACE TO THE SIXTH EDITION.

IN the preparation of the sixth edition of this little work, the Author has taken advantage of the opportunity to incorporate a large amount of new material, the introduction of which in a new chapter gives illustration of the rapid and important developments of even the short period which has intervened since the publication of the preceding edition. The general introduction of the direct-connected steam-engine, with its attached generator, has been a step in advance, in certain departments of construction and application, in practice, which has been, in a way, paralleled by the progress made in the analysis and development of the calorimetric and dynamic flow of energy through the machine, as a matter of applied science. Both these developments illustrate admirably the extent to which the work of the engineer is coming to be scientific and theoretically exact.

Every steam-engine, like all other forms of machinery, may be said to consist of an ideal, theoretically perfect, apparatus overlaid by faults and embarrassed in its operation by the impeding interaction of conflicting natural, physical, laws. The art of improving is that of elevating

the ideal, and of pruning away the defects of the actual, practical, construction. The ideal, purely thermodynamic, heat-engine has now come to be clearly and accurately distinguished within the faulty actual machine. It has been, knowingly or unknowingly, steadily improved since the days of Watt, and earlier, and the best modern practice brings us to a construction of the real engine, which consists of about two-thirds ideal and one-third real, practical, defect. The method of discriminating between the limiting and "perfect" engine, revealed by Carnot and by Rankine and Clausius, is now so far itself perfected to permit the magnitude and nature of all the defects of the steam-engine to be determined, and this "calorimetric analysis," originally due to Hirn and later brought into practical employment in the scientific work of the engineer, is exemplified by the several cases which have been imported into the sixth edition of this book.

The practical construction and performance of the machine, in its latest forms, may be studied in the text, and its illustrations, in the now newly inserted pages, and the various systems of direct-connection, and of engine-construction appropriate to them, as exhibited in the standard practice of the leading builders, constitute the essential and important recent improvements here described. They have been brought into the new edition as fully as the originally intended scope and character of the publication permitted. For the algebraic theory and mathematical physics of the subject the reader is referred to the works appropriated to that somewhat abstruse branch of applied mechanics.

On reviewing the whole history of the engine to date, it will be seen that progress continues in the directions already pointed out and towards still higher steam-pressures, higher speeds of piston and of rotation, increased ratios of expansion in multiple-cylinder engines, and with constant reduction of the now well-understood waste which distinguish the real from the ideal steam-engine.

The Publishers have, in this edition, effected a great improvement in the matter of book-making, by enlarging its page; securing thus broader margins and a vastly more satisfactory volume both to the eye and to the hand. They unite with the Author in cordially acknowledging a real indebtedness to those engineers, engine-builders, and business firms who have so liberally and promptly aided them in the endeavor to make the sixth edition of this work thoroughly modern, by supplying all information sought from them, and in so many ways facilitating the work of effective revision and extension. It is also a pleasure, as well as a duty, on the part of both Author and Publishers, to make hearty acknowledgment of their debt to that class of readers, extensive and evidently appreciative, if not always claiming to rank as mathematicians or men of science, who find sufficient instruction and enough of interest in a semi-popular work of this character to call for six editions in so short a period. It is hoped that equal satisfaction may be given in subsequent editions—if they should be called for during the remaining years of the life of the steam-engine in the character of man's greatest and grandest aid in energy-transformation for useful purposes.

February, 1899.

CONTENTS.

STEAM ENGINES

FOR ELECTRIC LIGHTING PLANTS.

I.

Historical—The Development of the Steam Engine.

THE growth of the steam engine into the forms now familiar to everyone who takes the slightest interest in this most important of modern mechanisms, has occurred by a series of transitions which is easily traced, and which is especially interesting to every thoughtful mechanic as representing the steps in a steady progression, toward ideal perfection, of which the end is not yet seen.

A century ago, James Watt had just begun to introduce the first engines belonging to a, then, new type.[1] A century before (1698), the ingenuity and practical skill of Captain Savery, had conferred an enormous benefit upon the mining industries, and through them upon the world, by applying the "fire engine" of the Marquis of Worcester to raising water from the then rapidly deepening mines.[2] Savery used steam of 8 to 10 atmospheres (120 to 150 pounds) total pressure, in some cases,and he is entitled to fame as the first to introduce that now familiar concomitant of civilization, the

1. History of the Growth of the Steam Engine. International Series. N. Y., D. Appleton & Co.

2. Consult Manual of the Steam Engine, Vol. I., Chap. I., for more of detail relating to the history of the subject.

steam boiler explosion. The usual pressure was 3 atmospheres. These engines demanded about 30 pounds of coal, per horse-power per hour, as a minimum. The apparatus of Savery was not what would to-day be called a steam engine, at all. It was not a train of mechanism, involving moving parts, cylinder, piston, crank and fly-wheel, but either a single pair of closed vessels, or three vessels, one of which was a boiler, and the other, or others, metal chambers of spherical, cylindrical, or ellipsoidal form, which were at once condensers and pumps. The latter were filled with steam, which being condensed, the water rose into, and filled them, and was then forced out by a succeeding charge of steam, of pressure exceeding that of the head against which the lift took place. Huyghens (1680), and Papin (1690), proposed true engines with steam pistons traversing their cylinders, and forming, on the whole, much such a train of mechanism as is now so well known[3]; but the Newcomen engine was the first of this type to come into practical use. This machine, then called the "Atmospheric Steam Engine," consisted of a steam cylinder, with a piston taking steam beneath, the upper end of the cylinder being open to the atmosphere, the piston actuating a "working beam," or "walking beam," and, through the latter, working pumps attached to the opposite end. Neither crank, shaft, nor fly-wheel was used; the action of the engine was controlled entirely by the adjustment of its valves. In its operation, steam at a little higher than atmospheric pressure, was admitted below the piston; the weight at the pump end depressed that extremity of the beam, raising the piston.

3. Mem. Acad. Sci. Paris, 1680. Acta Eruditorum. Leipsic, 1690.

The steam below the piston was then condensed by a jet of water thrown into the cylinder, producing a vacuum; and atmospheric pressure finally forced the piston down, raising the pump-rod and plungers. The weight on the latter was adjusted to the work, so that, when steam was admitted, this weight should force the pumps to discharge the water. The only function of the steam was the displacement of the atmosphere, or counterbalancing it, by entering below the piston, and thus permitting the formation of a vacuum. A writer of that time states[4] that "Mr. Newcomen's invention of the fire engine, enabled us to sink our mines to twice the depth we could formerly do, by any other machinery"; but "every fire engine of magnitude consumes £3,000 worth of coal per annum." The coal consumption was, at best, about 20 pounds per hour and per horse-power. Smeaton, the greatest civil engineer of his time, put up many of these engines in Holland and elsewhere, as well as in Great Britain; some were 66 inches in diameter of cylinder, and 8 to 9 feet stroke of piston. It was this engine that Watt found in operation, when he entered upon the stage.

Watt was not simply a mechanic; he was a real philosopher, and a truly scientific investigator. A model Newcomen engine, having been brought to him to be repaired, he took advantage of the opportunity to study the principles of its construction, to ascertain its defects, and to devise proper remedies. He found that the sources of loss were the conductivity, and radiating power of the steam cylinder, the alternate heating and cooling of the metal at each stroke, the imperfect vacuum, and the wastes from boiler and

4. *Mineralogia Cornubiensis.* Price. 1778. Appendix.

steam pipes. To correct these defects, he clothed his boilers and steam pipes with non-conductors, sometimes even making boiler shells of wood. Smeaton had already covered the pistons and cylinder heads with wood. Watt made a small wooden steam cylinder, and obtained great economy; he made a more practicable improvement, however, when he devised the steam jacket. He attached a separate condenser to prevent the loss due to the introduction of condensing water into the steam cylinder, closed the cylinder at the top, made the engine double-acting, and finally adapted the engine to drive machinery, fitting it with shaft and fly-wheel, throttle valve, and governor, and thus making the steam engine such as we see it to-day, in all essential particulars, not excepting the steam jacket, and the arrangement of its valve gear to secure economy by the expansion of the steam. His engine was substantially complete by the year 1784.[5]

Later changes have been a succession of refinements, and of developments in application. Stephenson, and his contemporaries, applied steam on railroads; Stevens, Fitch, and Evans, and, finally, Fulton, in the United States, and Bell and others, in Europe, introduced steam navigation; Sickels invented the "detachable" cut-off valve gear; Corliss introduced the peculiar type of engine that has given him a world-wide fame, and so attached its governor as to determine the point of cut-off automatically, and thus to regulate the engine; and, a little earlier, Robert L. and Francis B. Stevens designed the American river steamboat, and its beam engine, with so simple and effective a valve

5. History of the Growth of the Steam Engine. P. 119. Farey on St. Engine.

gear that it remains, to-day, still standard. The compound engine, even, was brought out by contemporaries of Watt, and thus every prominent feature and essential detail of the modern steam engine was introduced at, or before, the middle of the nineteenth century.

Yet, practice has been steadily changing during the century, and the form and proportions of the steam engine, and the methods of steam distribution, have been undergoing constant changes. In the time of Watt, steam was worked at about 7 pounds pressure, per square inch, in stationary engines; they were always fitted with condenser and air-pump, and were slow in movement, and were, consequently, of small power in proportion to their size; they wasted heat and fuel to such an extent, as to demand 6 or 8 pounds of coal per horse-power and per hour. It is true that Wolff, in 1804, expanded 6 or 8 times, using higher steam and obtained the horse-power with 4 pounds of fuel per hour, and that John Stevens and Oliver Evans, in the United States, and Trevithick, in Great Britain, had already used still higher steam in non-condensing engines; but these examples simply illustrated the fact, now familiar to every student of philosophical history, as pictured by Draper, Buckle and Whewell, that isolated examples which lead standard practice by a half century or more, are to be observed during the growth of every art. Recognized standard practice is always as conservative as it is permitted to be by trade competition, and usually changes very slowly. Principles may be discovered and understood, and a correct theory of design and of practice may be made generally familiar, and often is, in a brief period; but the growth of application

and the familiarizing of constructors and operatives with new mechanisms, and new methods of management, requires time, and is slow at best. Thus it has happened, that although the principles of steam engine economy were, in the main, well understood by James Watt, and some of his competitors, nearly a century ago, and have become well settled in later years, we are still far from a completely satisfactory solution of the problem, which, as stated by the writer elsewhere, may be enunciated thus:—"To construct a machine which shall, in the most perfect manner possible, convert the energy of heat into mechanical power, the heat being derived from the combustion of fuel, and steam being the receiver and conveyer of that heat."

II.

Principles of Economy; Special Requirements.

THE principles of economical working, noted by James Watt, and plainly stated by him, were but slowly recognized by others, and the improvement of the steam engine was, for many years, correspondingly slow. The principles that must govern the engineer, in the attempt to secure highest efficiency, may be summarized thus:

1. The greatest practicable range of commercially economical expansive working of steam must be adopted; the fluid must enter the cylinder at the highest admissible pressure, and must be expanded down to the minimum economical pressure at exhaust.

2. The wastes of heat must be made the least possible; all loss of heat by conduction and radiation from the engine must be prevented, if possible, and the usually much more serious waste which occurs within the engine, by transfer of heat from the steam side to the exhaust, by "cylinder condensation" and re-evaporation, without doing its proportion of work, must be checked as completely as is practicable. This latter condition, as well as commercial considerations, limits the degree of expansion allowable. It also dictates high speed of engine.

3. The largest amount of work must be done by the engine that it can perform, with due regard to the preceding conditions. This condition compels us to drive the engine up to the highest safe speed, and to adopt the highest practicable mean steam pressure.

The first two of the above requirements give maximum efficiency of fluid, consistent with commercial economy, and the latter gives highest efficiency of machine. In addition to these requisites, which are not peculiar to any style of engine, or to any one of the innumerable applications of steam power, the adaptation of the machine to driving the dynamo-electric apparatus of an electric lighting plant, compels the designing and constructing engineer to meet certain demands which, although not peculiar to this work, are, nevertheless, more imperative here than elsewhere. The principal of these requirements are effective regulation, compactness, simplicity of parts, strength and durability, and small cost, both of original purchase and of repairs. In the attempt to meet these demands, the modern "high speed engine" has gradually taken shape.

In the time of Watt, a pressure of seven pounds of steam, with condensation, and a low piston speed, equal, usually, in feet per minute, to about one hundred and twenty-eight times the cube root of the length of stroke, according to Watt's own rule, represented standard practice. As time went on, steam pressures and piston speeds gradually rose, and when, in 1849, Corliss brought out the typical modern "*Drop Cut-off Engine*," pressures of sixty pounds, and speeds of piston reaching 450 feet per minute were becoming usual. At such speeds, the "drop cut-off" was thoroughly effective, and the steam valve, detached from the driving mechanism, fell into its seat with sufficient promptness and accuracy, as to time of closing, to do good work; the governor had no other work to do than to detach the valve, and was thus able to regulate with an exactness

that is still beyond competition. These engines are very extensively used to drive the smaller electric light machines, and particularly where a considerable number are to be driven together; they are not adapted to the work of driving the large "dynamo," where it is desired to couple direct from crank-shaft to armature.

As piston speeds increased, the drop cut-off became less satisfactory, where the load was variable. It became slowly understood, among builders and users of engines, that one important element of economy of fuel and cheapness in cost of engine is the maximum speed of engine consistent with endurance and safety. Speeds were, after a time, rapidly increased, the Porter-Allen engine leading in this movement, and small engines, working at high speed, displaced large engines of the older type. It soon became evident that this change must lead to the re-introduction of the "positive motion" classes of valve gear and expansion gear that Sickles, Corliss and Green had temporarily displaced, notwithstanding the fact that these builders had greatly increased the speeds of their engines. All the so-called "high-speed engines," which are best known in the market, are of this later type. The slower running engines are nearly all fitted with governors of the fly-ball class, geared, or belted, to revolve at a much higher speed than the engine itself; but the great velocity of rotation of the new engines, from 200 to 500 revolutions per minute, in the small sizes, and often a piston speed of about 800 times the cube root of stroke, permits the attachment of the governor directly to the shaft; and this is done in the later styles. This change of position of the governor, in turn,

has led to a change in its construction. The balls, instead of being hung from a vertical revolving spindle by arms pivoted on that spindle, are attached to arms carried on the main shaft, or the driving pulley, and revolve in a vertical plane at right angles to the shaft; they are held in place against the action of centrifugal force by springs, and arranged to adjust the eccentric, and to vary the expansion, in a manner which will be plainly seen when studying their construction in the later sections of this paper, in which these engines will be described with the aid of carefully made engravings. The high speed engine, as adapted to the work of directly driving the "dynamo," therefore, may be described as a high pressure, non-condensing engine, of short stroke, and high speed of rotation, with a positive-motion valve-gear, and regulated by a governor, which is usually mounted on the shaft, and so attached as to alter the expansion by varying the lead of the valve. Its essential features are high speed of rotation, good regulation by a positive gear, economy, simplicity, and compactness. It is this engine only, which is found to do good work under these peculiarly exacting conditions.

It is proposed to study the best known engines of this and the earlier classes, and to compare them, with a view to bringing out their peculiarities and their special merits, while the purchaser will, besides, study the machine which he proposes to buy, to determine whether its material and workmanship are as excellent as are the principles of its design.

The conditions demanded can here be merely outlined, in the following resumé[1] of the requisites of successful practice:

1. Report on Machinery and Manufactures. R. H. Thurston. Vol. iii. Reports of the Scientific Commissioners of the United States to Vienna; 1873.

1. A good design, by which is meant:

a. Correct proportions, both in general dimensions and arrangements of parts, and proper forms and sizes of details to withstand safely the forces which may be expected to come upon them.

b. A general plan which embodies the recognized practice of good engineering.

c. Adaptation to the specific work to be performed, in size and in efficiency. It sometimes happens that good practice dictates the use of a comparatively un-economical design.

2. Good construction, by which is meant:

a. The use of good material.

b. Accurate workmanship.

c. Skillful fitting and a proper "assemblage" of parts.

3. Proper connection with its work, that it may do that work under the conditions assumed in its design.

4. Skillful management.

In the endeavor to secure these requisites, it is generally advisable to use steam at a pressure not far from one hundred pounds per square inch. The benefits of increasing pressure diminish so rapidly above this point, that it is not yet certain whether it will, with the simple engine, pay to carry pressure much higher. The ratio of expansion is to be determined with reference to this pressure, as well as to size of engine. It will usually be found even more wasteful to cut-off too short than to "follow" too far; and Rankine's principle of adjusting this point by consideration of the relative cost of large and small engines, as well as the princi-

ples controlling the economy of fuel, dictate, that for these engines, which are nearly always non-condensing and unjacketed, the ratio of expansion must usually be low—say from three to five, as higher pressures range from sixty to one hundred pounds per square inch[2]—and that the terminal pressure shall usually be kept some five or six pounds above that of the atmosphere.

Moderate "superheating" is found advantageous; but it is seldom carried beyond about a hundred degrees above the normal temperature of the steam. "Steam jacketing," as practiced in nearly all compound engines, is of advantage; but is not usually considered to pay for the added cost and risk in engines of the class here considered, and especially in high-speed engines. The "compound" engine has now found a place in this field. Smeaton's idea—or rather Watt's, first attempted on a large scale by Smeaton—of surrounding the working fluid with non-conducting surfaces, is not yet found practicable with the high steam pressures and temperatures now usual. Its final adoption, however, is beyond doubt, as it is a far more promising system of economizing heat, now wasted, than either superheating or steam jacketing. The latter, indeed, is a method of introducing a waste to check greater loss.

Careful protection of external heated surfaces of the cylinder against losses by conduction or radiation, is always practiced where it can be conveniently done, and parts which cannot well be so covered are highly polished. A well polished surface transmits very little heat.

Back pressure, a frequent cause of waste of power, is

2. Manual of the Steam Engine, Vol. I. § 25.

reduced by making the exhaust parts large, and the exhaust opening of the valve rapid, and by giving "lead" to the exhaust, so that the steam shall leave the cylinder just before, rather than just after, the return stroke begins.

Friction is reduced to a minimum by carefully proportioning the journals, and by securing free and continuous lubrication with a good oil or grease.

An engine in which all the above requirements are fully met is certain to be a good machine.

It is not proposed to compare the steam engine with the gas engine, or with other motors. The gas engine is, in many cases, likely to prove useful in consequence of its compactness, cheapness of first cost, freedom from risk, and small expense for attendance ; but it is expensive in use of fuel, and is rarely as little liable to annoying interruptions of operation as the steam engine, and also possesses other minor disadvantages. Nevertheless, Otto and Clerk, and other inventors and constructors, have greatly improved this machine of late, and have brought the expenditure, in ten-horse engines, down to twenty cubic feet of gas, or less, per hour and per horse-power ; and although this is still double the theoretical figure, no one can say how soon the latter consumption may not be much more closely approximated to. The gas engine is certain to find work in this direction. Hot air engines, as yet, give less promise ; but it would be rash to predict their total exclusion from the field.

Water-wheels, especially when used exclusively for supplying power to the lighting plant, are, where available, thoroughly satisfactory prime movers.

In studying the steam engine from the standpoint here

taken, we will divide them, first, with reference to their method of driving the dynamo-electric machine, into two classes :

1. Engines which may be used in driving by belt, and which are not adapted for direct connection.

2. Engines especially designed and constructed to be coupled directly to the "dynamo."

The first class of engines is in very extensive use, and is, by many of the more conservative engineers, still preferred to the second. The latter constitute the so-called "modern" type of engine, and are gradually coming into use, some engineers adopting them, both for direct and for indirect connection. The best engineers are not yet fully in accord in regard to the question, whether they have passed the experimental stage.

The great changes marking the approach of the twentieth century are the general introduction of the multiple-cylinder engines having two or three and even four cylinders "in series," and the direct connection of the driving-engine with the driven electrical generator; both having a common shaft, or shafts directly coupled, in such manner that both machines shall be employed at the same speed of rotation and all belting or gearing connections then eliminated, giving thus a gain in simplicity and with great economy of floor-space.

III.

Engines Indirectly Connected, only.

THE CORLISS ENGINE.

DIVIDING engines used in driving dynamo-electric machines into two principal classes—engines driving indirectly through gearing or belting, and engines directly connected to the armatures—we may profitably devote considerable space to the first class. And, although machines of the kind which have come to be distinguished by the appellation "high-speed engines" may be, and often are, indirectly connected, it is proposed to leave the examination of such engines to a later article on directly connected engines, and here to describe only the "drop-cut-off" engines, or those with "detachable valve-gear," which can only drive the armature of the "dynamo" indirectly.

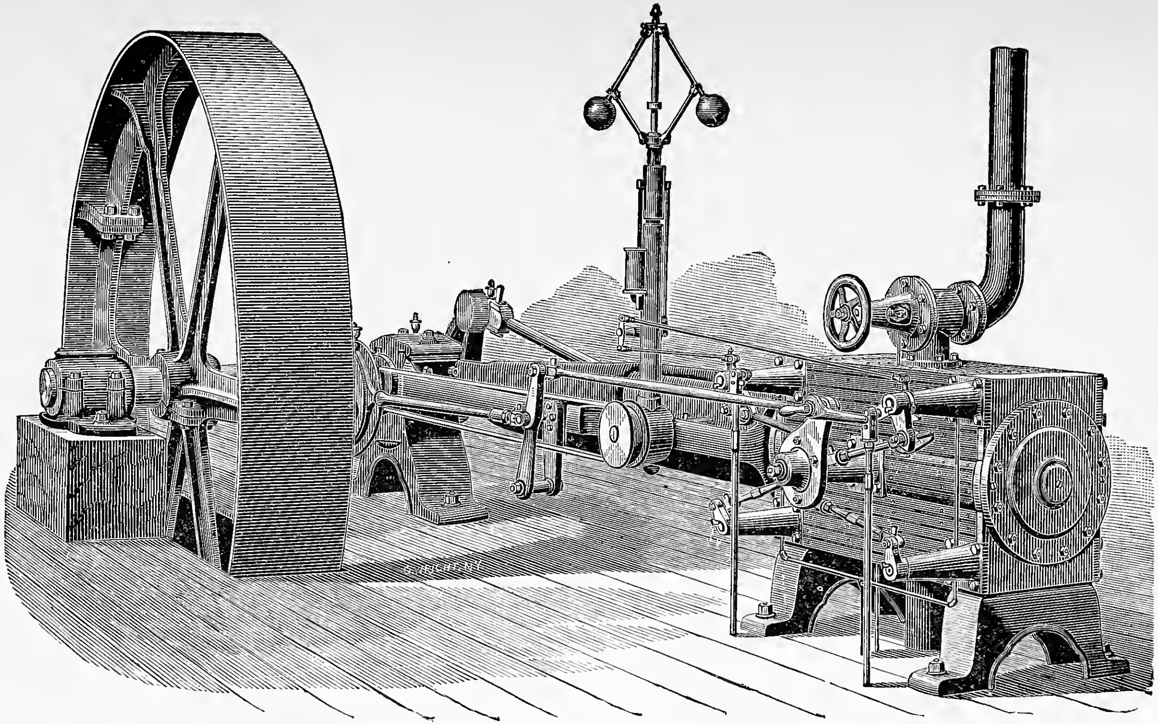
The first drop cut-off introduced, had a form patented by Fred. E. Sickles, in 1841. This engine was first built for mill purposes, by Thurston, Gardner & Co., at Providence, R. I., that firm then holding the Sickles' patents, except that the marine engine business was retained by Sickles. The modern stationary engine was thus introduced, and was soon extensively made known among steam users by its superior performance when competing with the older engines, which were then usually arranged to expand steam about one and a half times by the lap of the single three-ported valve. A few engines were built of a better design, fitted with an independent cut-off valve on the back of the main

valve. These two last named engines would, at best, with good boilers use five or six pounds of coal per hour, and per horse-power, where the Sickles valve-gear would bring the consumption down to four.

Regulation was always effected by a governor controlling a throttle valve. This governor was usually a common fly-ball governor, and its deficiency in power and lack of isochronism, the distance of the regulating valve from the engine valves, and the range of motion required in its operation, and the resistance offered by the packing of the steam, altogether, made this combination a very ineffective regulating apparatus. Thurston, Gardner & Co., substituted for this the Pitcher hydraulic regulator and a register valve, which gave a much better regulation; this contrivance was also isochronous, *i. e.*, it was capable of holding the engine at speed, whatever the variation of steam-pressure or of load.

But an immense step in advance of this, then, best practice was made by Geo. H. Corliss, a young Providence mechanic, who had exchanged the *rôle* of sewing-machine inventor for that of the inventor of the most famous steam engine that has appeared since the time of Watt. The Corliss engine was patented in 1849, and rapidly came into use, its remarkable economy, when competing with the best existing engines, the peculiar business tactics of its builder, and the rapidly increasing demand for efficient, and especially well regulated, engines, combining to give it a wonderfully rapid introduction.

The engine is an interesting illustration of a machine which is the representative of a peculiar type, each detail



THE CORLISS ENGINE.

of which is especially adapted to its place in that machine, and is characteristically different from the parts which perform the same office in other engines. The leading features of this machine are:

1. The use of four valves—two steam, and two exhaust—so placed as to reduce "clearance" to a minimum.

2. The use of a rotating valve, capable of being cheaply and readily fitted up, of being easily moved, and of being conveniently worked by connections outside the steam spaces.

3. The use of a "wrist-plate," caused to oscillate by a single eccentric, and directly so connected with all four valves that each may be given a rapid opening and closing movement, and be held open and nearly still, at either end of its range, by swinging the line of connection nearly into the line between centres, thus permitting nearly a full opening of port to be maintained during an appreciable interval, and a free and complete steam supply and exhaust.

4. A beautifully simple and effective method of detaching the steam valve from the driving mechanism, and of insuring its rapid and certain closure at the proper moment, to produce any desired expansion of steam.

5. A direct connection of the governor, so as to determine the ratio of expansion, while so adjusting the power of the engine to the work to be done, that the variation of speed with changing loads becomes a minimum.

6. Making this latter adjustment in such a way as to throw the least possible work on the regulating mechanism, and thus to give the governor the greatest possible sensitiveness and accuracy of action.

7. A form of frame and general design of engine, which gives maximum strength and stiffness, with least cost and weight.

All these features are combined to form a steam engine essentially different, in general and in detail, from the engines contemporary with or succeeding it, except where the latter may properly be classed as Corliss engines. It rarely happens that an inventor succeeds in originating a plan so wholly and so essentially novel; and it is still less frequently the fact, that a peculiarly original device is found superior to all competing machines. In operation, the engine was found to exhibit a remarkable economy of fuel. and a singularly perfect regulation, and to be far more durable and more economical in cost of repairs, on the average, than rival builders supposed possible. It very soon took the leading place in the market.

The inventor established himself at Providence, and put in operation a method of marketing his machine which was as novel and as successful as the mechanical device itself. He offered to put his engine in place of rival engines, either with a guarantee of a certain saving, and at a stipulated price, or, often, to take as his compensation the actual saving shown on the books in a stated time. This system was eminently satisfactory to the purchaser, both as making him safe against loss, and as giving him some of that confidence in the engine which the maker himself unquestionably possessed. Corliss' work fully justified his claims, and the expenditure of fuel was brought down to between three and four pounds per hour, and per horse-power, according to size and situation of the engine,

with occasionally much better figures in condensing engines.

This engine is now built, not only by the Corliss Steam Engine Co., under the eye of the inventor, but by many other builders. It has found its way into every part of the world ; and the engineer visiting Europe will find a pleasure in observing the general adoption of this American invention in every country, and for every purpose. European makers frequently modify the design, but rarely with the desired effect of securing an improvement in cost or efficiency, and very often with a decidedly contrary result.

Corliss engines are now very frequently adopted in electric lighting, and are always belted to the dynamos. Their excellent regulation is as important a feature in this application, as is their economy in use of steam. When carelessly constructed, they are, of course, likely to prove wasteful and irregular in action. But that these engines can be made to give very perfect uniformity of rotation will be evident, when it is stated that the writer, in testing engines of this class, has found that the variation of speed was so slight as to be practically inappreciable, even when the amount of work thrown on or off, was a very large proportion of that done by the engine when working at its rated power.

One other reason for the success of this engine is unquestionably the comparatively small cost of its construction, where competing with the earlier forms of engine with detachable valve-gear. Its valve-faces, particularly, and their seats, are surfaces of revolution, and they, as well as a large part of the finished work about the engine, being

almost wholly lathe-work, the cost of fitting up is comparatively small.

In detail, the engine consists, as shown in the illustration, page 19, of one of its standard forms, of a steam-cylinder sustained by any substantial connection with the foundation. The main pillar-block sustains the crank-shaft at the opposite end of the machine, and a strong brace, connecting these two pieces, forms, at the same time, a support for the crosshead guides.

The four valves are placed at top and bottom of each end of the cylinder, their rotating stems projecting, and are moved by the "wrist-plate," set usually, as here, at the middle of the cylinder, the valve connections radiating to the four corners, where each is attached to the valve rocking-arm, the exhaust by pin-connections, the steam by a catch, which can be readily "tripped" by the adjustment of a little cam set on the valve-stem, behind the arm. When tripped, the steam valves are closed by a spring, or in engines now built by Mr. Corliss, by a "vacuum-pot," and by weights in his earlier engines, and in those of other builders.

The governor is belted from a pulley on the main-shaft, and its oscillations are controlled by a "dash-pot," seen attached to the side of its standard. The governor, having no work to do but to set the tripping-cam, or the equivalent for it adopted by Corliss and others in various designs, is entirely free to adjust itself to the normal position due the speed of the engine, and thus is made perfectly capable of doing the best possible work Many foreign builders have attached the Porter loaded governor to this engine. The

advantage is less obvious here than in engines in which more strength of action is needed.

From what has been stated, it is seen that the Corliss engine came into use in consequence of its combination, to an extent up to that time unequalled, of several special features. Some of these points are not necessarily peculiar to the Corliss type of engine; but they, nevertheless, were peculiar to that engine at the time of its introduction. The main points were: the rapid and wide opening of the steam and exhaust openings; the shortness and directness of the ports; the resulting small clearance and "dead" spaces; the quickness of closure of the steam valves; the adaptation of the main valve to the functions of a cut-off valve; the connection of the governor to the cut-off gear in such a manner as to determine the point of cut-off without being itself hampered by the connection; the location of the exhaust ports at the under side of the cylinder so as to drain the cylinder thoroughly; and the simple, easily constructed form of the machine and of its details.

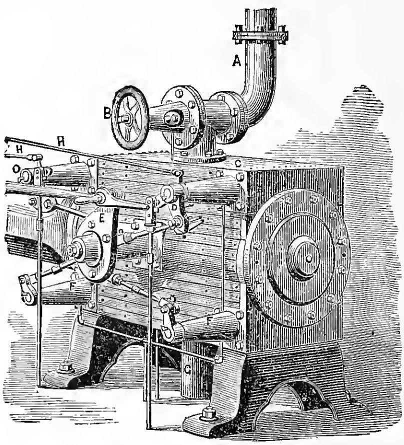
The general form of the engine has been preserved by nearly all builders, and the parts of the valve gear and details of regulating mechanism have been seldom much modified. A few builders have, however, made changes which are worthy of notice, but which we have not time or space to study as they deserve.

The action of the Corliss engine is as follows:[1]

The valves are driven by the eccentric rod through the "wrist-plate," *E*, vibrating on a pin projecting from the

1. Manual of the Steam Engine, Vol. I. § 34.

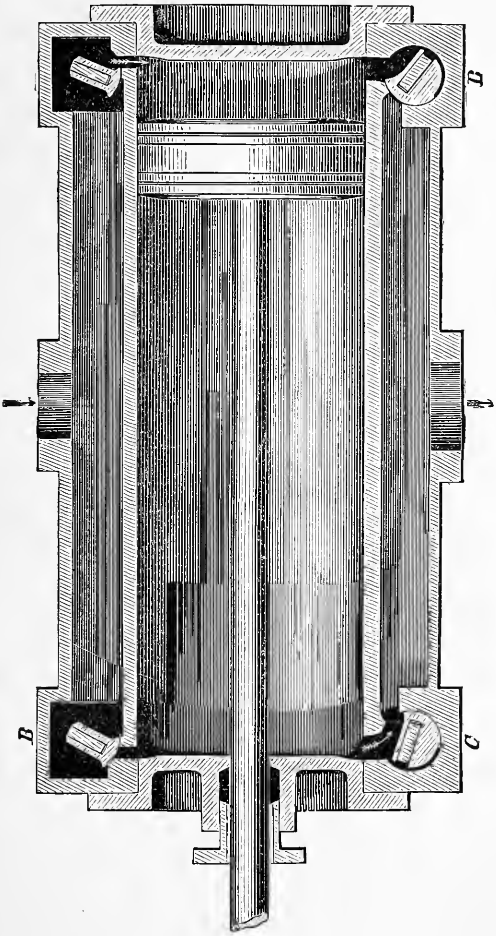
cylinder. Links, *E D*, *E D*, *E F*, *E F*, take motion, from properly set pins on this wrist-plate, to the steam valve rock-shafts, *D*, *D*, and to the exhaust valves, *F*, *F*, moving them with a peculiar varying motion in such a manner as to open and close the ports rapidly, and to hold them open, when the valves are off the ports, in such a way as to give the least possible loss of pressure during the exit or the entrance of steam. The links leading to the steam valves are fitted



THE CORLISS ENGINE.

with catches, or latches, which may be disengaged, as the valve opens, at any desired point within about half stroke; and the time of this disengagement is determined by the rotation of a cam seen on the valve stem above *D*, which cam is rotated by the governor through the rod *H*, leading off to the left. The slowing of the engine, in consequence of reduced steam pressure or of increased load, causes the catch to hold its contact longer and the steam to follow

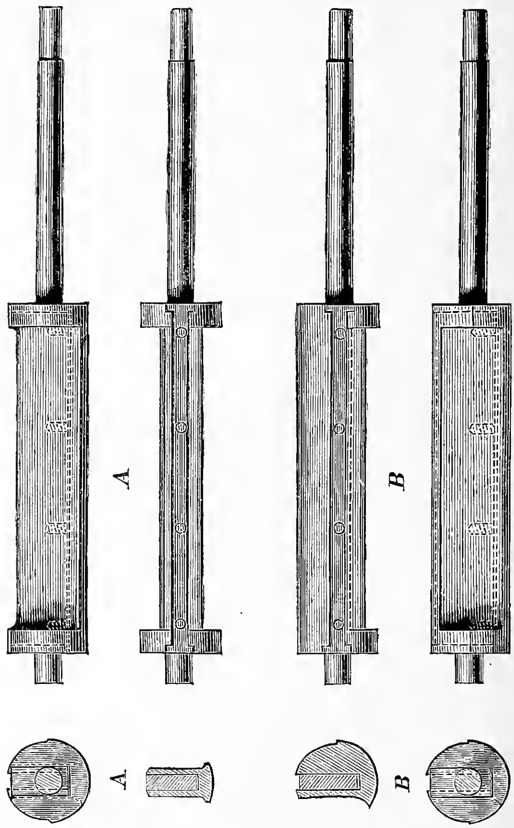
farther, and the reverse. When the catch is disengaged, the valve is closed by a spring or weight attached to the



THE CORLISS ENGINE CYLINDER.

vertical rods seen connected to the rock-shaft arm. Corliss uses a device in place of this which is not here shown. The

dash-pots are under the floor, in the case here illustrated, or on the column supporting the governor in the engines just referred to. It is always an air dash-pot. The device invented by Sickles was a water dash-pot.

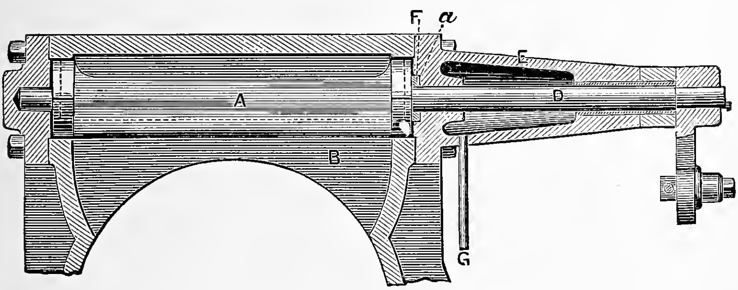


CORLISS ENGINE VALVES.

The standard form of Corliss valve is very well exhibited by the illustrations here given, which are taken from the drawings of Mr. Harris.

Those marked *A* are the steam, and those marked *B* are the exhaust valves. Both consist, as is seen, of cylinders, parts of which have been cut away, leaving the working and bearing surfaces of no greater extent than is necessary to subserve the purposes of the valve. These surfaces are of the simplest possible form and are easily fitted up in the lathe. In order that they may come to a bearing with certainty, and without regard to the position of the spindle relatively to the valve, they are made with a longitudinal slit into which fits, without jamming, the blade of the rock-shaft. The valves are thus allowed to come to a bearing, and even to wear down in their seats without causing leakage.

The next Fig. shows the arrangement of this valve as seen in longitudinal section of the chest. As this maker

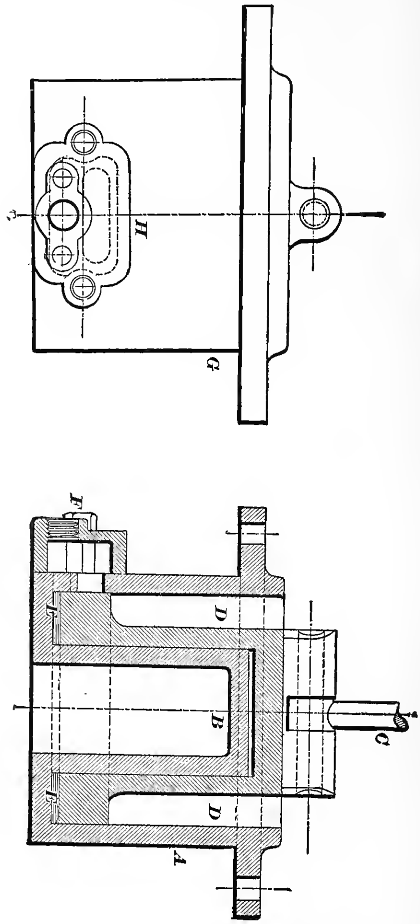


HARRIS-CORLISS VALVE.

constructs it, the stem goes through a fitted opening, without stuffing box, and the slight drip is carried off from the closed space at *D*; thus none escapes into the engine room. The steel collar at *F*, which is shrunk on the stem, fits into the recess at *a* and serves as a packing. As the tendency of the stem to shift outward always causes

the collar to wear to a fit, it is not likely often to wear leaky.

Another detail of interest in the Corliss engine is the



THE DASH-POT.

"dash-pot." When the valve is suddenly closed, some device is necessary to prevent jar at the instant of its com-

ing to rest. This device is the dash-pot. The form adopted by Corliss consists of a shallow cup into which a piston on the valve stem fits, cushioning the enclosed air, and thus checking the motion of the valve without shock. This dash-pot, made by Watts, Campbell & Co., who have successfully introduced Corliss engines into electric light establishments in New York city and elsewhere, is that seen in the Figs.

The annular piston, *E*, *E*, fits the cylinder, *D*, *D*, *E*, *E*, and a space, seen above *B*, forms a vacuum chamber which assists the spring or weight, closing the valve by the formation of a more or less complete vacuum, as the piston is raised while the valve is opening. A small cock, not seen, is arranged to adjust the degree of exhaustion of this chamber. When the valve has nearly reached its seat, the piston *D*, passes the opening from ***F*** into the outer space and the enclosed air then acts as a cushion, checking the movement of the valve. In the engines of these builders, great care is taken to keep the cold exhaust steam clear from the cylinder as it passes out, in order to prevent the condensation which occurs where this precaution is neglected.

Many Corliss engines are already at work driving electric lighting apparatus, and are giving good satisfaction, according to the testimony given the writer by the officers of the companies using them. One, built by the Corliss Steam Engine Co., is at work at Providence, R. I., driving many dynamos, and a number are in use in New York city, and other large cities of the United States and of Europe.

At how high a speed they can be operated with satisfaction to the user is not definitely known. The writer has

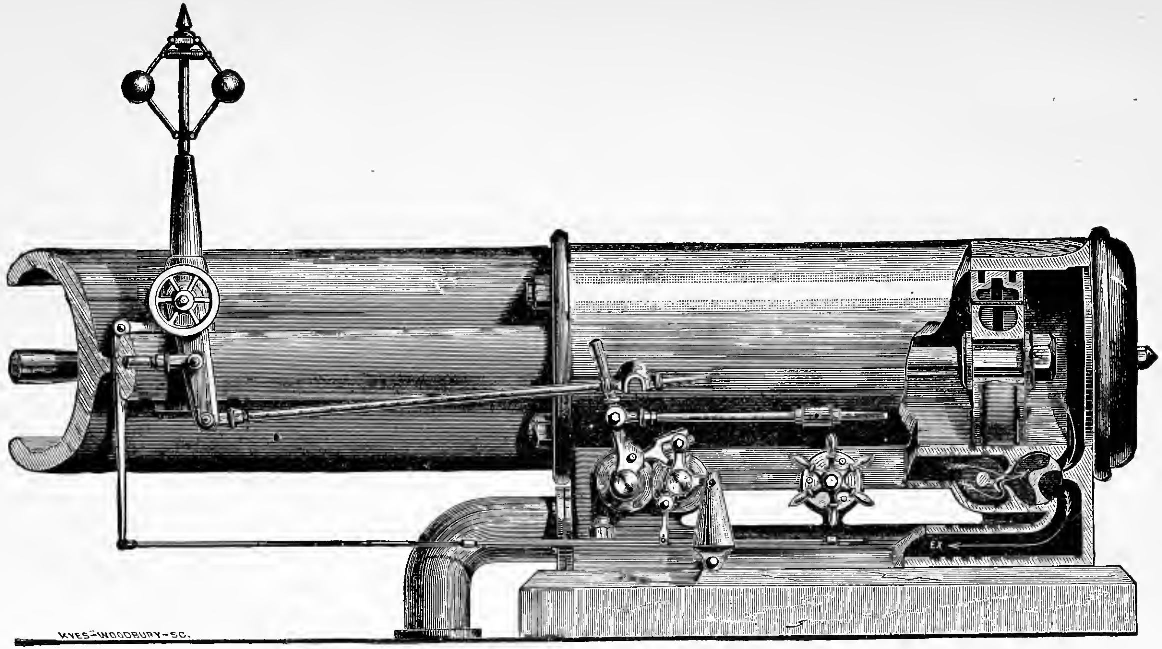
known one of these engines, coupled to a fast running roll-train, to be driven without apparent difficulty for several years at a speed of 160 revolutions per minute, although of four feet stroke. This engine is still running. Those who use, as well as the engineers who build, this class of engines, however, are apt to be conservative and to prefer the moderate speeds with indefinite endurance, to higher speeds with a shorter life of engine and greater cost in keeping in repair; and to consider that the satisfaction of having a prime motor, which is not likely during their business lives to give them any trouble, is more than a compensation for any possible saving in dollars and cents to be effected by the adoption of the higher velocities of piston and of crank-shaft rotation.

THE WHEELOCK ENGINE

is an ingeniously arranged engine of the class considered in this division of the subject.

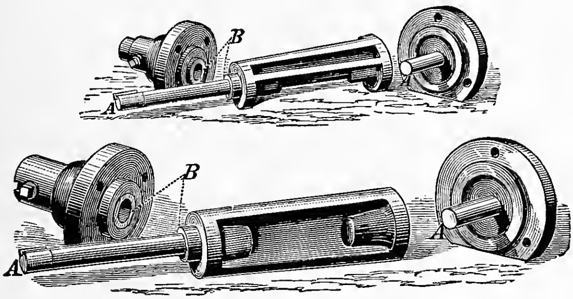
Its form is seen in the accompanying engravings.

The steam chest is placed below the cylinder and the steam and exhaust valves are set side by side, the latter serving both as induction and eduction valve, and having the same action, nearly, as the common three ported slide valve, while the function of the former is principally that of a cut-off valve. The latter, or main valve, is set nearest the end of the cylinder and the exhaust steam is thus permitted to escape directly and promptly from the engine. The valves are coned, slightly, and may be adjusted to take up wear, or to relieve pressure on their seats. These valves



THE WHEELOCK ENGINE.

are carried on steel trunnions, and with hardened surfaces of contact are but little subject to wear. The steam or cut-off valve is set further away from the cylinder than in the standard arrangements of Corliss and other builders of that class of engines, and this enables the maker of this engine to secure a single port with reduced clearance and less liability to leakage, should the expansion valve leak. In this engine—and it should be the case in every engine in which the regulator is driven by belt—the connection from shaft to governor is so made that the breaking of the belt permits an automatic closing of the valve and the stopping



THE WHEELOCK VALVES.

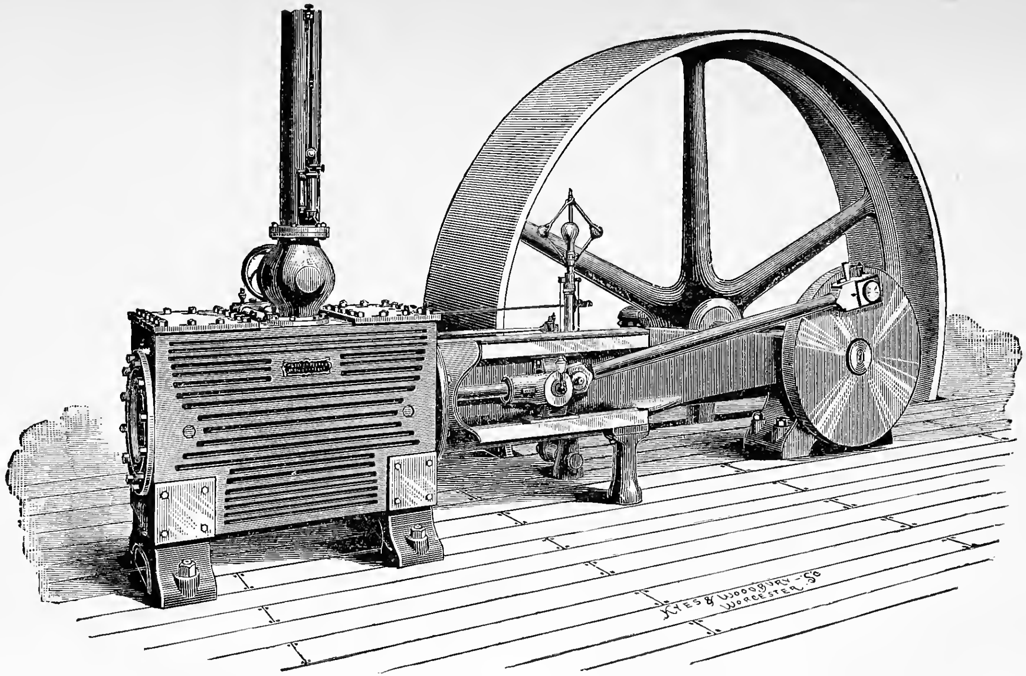
of the engine. The regularity of motion of the class of engines described in this section, may be inferred from the fact stated in regard to the engine here studied, that it has been known to vary but a half revolution per minute when five-sixths of the load was thrown off.

Engines of the class described in this section have displayed an economy in the use of fuel that has been rarely excelled by the best type of compound engine, working under the same conditions of steam supply. With good

boilers, they have given the horse-power with a consumption of two pounds an hour for condensing engines, and three pounds for non-condensing engines. They have quite often demanded but a ton of coal for 100 barrels of flour ground, in well arranged mills; and one and a quarter tons is a very usual figure. A number of good makers are now building such engines, and the purchaser can readily suit himself if desirous of selecting an engine of any grade, either as to cost or excellence of construction. They are well adapted to driving either large or small electric lighting plants; and, if purchased of a reliable maker, may be confidently expected to give satisfaction.

THE GREENE ENGINE.

NEARLY all "drop cut-off engines" are constructed, like those described in the preceding article, with a single eccentric, which drives both the steam and the exhaust valves. Both sets of valves must, therefore, have the same motion relatively to the piston, except so far as their motion can be modified, as in the Corliss engine, by the method of connection of valve and eccentric. They must stop and start at the same instant, and their motion during their travel must be more or less similar. But such a system is controlled in its action by the necessary motion of the exhaust valve. That valve must be adjusted to open and to close very nearly at the beginning and the end of the return stroke, in order that the exhaust may be prompt and free, and that the compression shall be right. The movement of the gear, on the steam side,



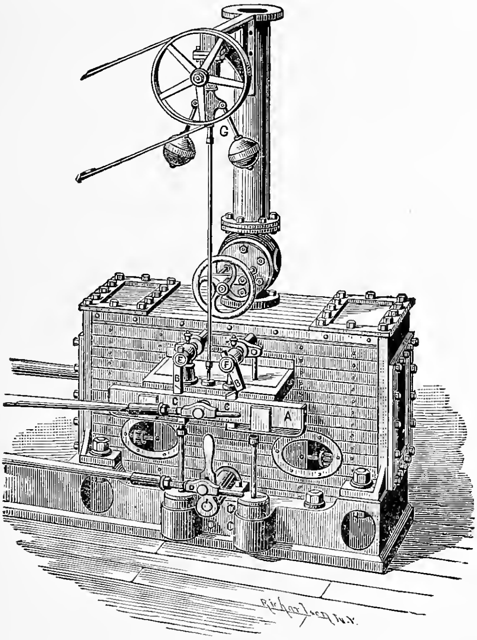
THE GREENE ENGINE.

must thus be also one which shall open the valve to take steam at the commencement of the steam stroke, and, if the valve is not tripped, close the port at the end of that stroke. It is further evident, that if the valve is to be detached by its own motion, it can only be tripped during the forward part of its movement, and that, passing that stage, and commencing to return before the cut-off takes place, the valve must be allowed to remain undetached until the end of stroke, and steam must follow full stroke. An engine thus constructed, and so adjusted to its work as to cut-off at about half stroke, will evidently, if the work or the steam pressure becomes variable, be likely to operate very irregularly, at one time cutting off at a little inside half stroke, and then jumping to full stroke. This variation of steam distribution may thus itself introduce a disturbing element, and the engine may give a very unsatisfactory performance. Such an adjustment of power of engine to the work to be done, does not often take place in engines of the class which is here studied, as the best point of cut-off is usually not far from one-third or one-fourth stroke, and the variation in the load is not often great enough to cause serious difficulty in the manner described above.

One advantage possessed by the arrangement of valve gear, thus subject to criticism, is that, should, as sometimes happens, the valve fail to close, or should it lag behind very greatly, in fast running engines, it is certain that it cannot be left open beyond the end of that stroke, as the returning motion of the valve-gear will bring the latch into gear again, and will insure its closing. Mr. Corliss considered this point of sufficient importance to make it inex-

pedient to drive the steam valves by the method to be described in this article. It is undoubtedly an advantage to be able to secure such an arrangement of valve-gear that the ratio of expansion may be varied by the governor from the beginning to the very end of the stroke, so that the engine may adapt its steam supply to any load that may be thrown upon it, whatever the extent of that variation may be, and to cut-off at any point from end to end of the stroke. This can be done by the adoption of a gear of the class known, for many years past, from the time of the earliest steam engines in fact, as the "plug-tree" form of valve-gear. It was this class of gear that was used on engines before the days of Watt, that greatest of inventors, for pumping out the deep mines of Great Britain—the Newcomen engine. It may be still seen in use on all so-called Cornish engines, which are to be found in the water works of this and other countries—the most costly, cumbersome, and unsatisfactory style of engine which has been applied to that kind of work in modern times. The distinguishing feature of this gear, is, that it is so adjusted, that the motion of the valve is produced by a mechanism which begins and ends its movement with the action of the piston; in the Cornish engine it is actuated by the engine beam. It is easy to obtain a motion of this character, by the use of an eccentric, by simply setting it so as to make its throw directly with, or opposite to, the crank. In such a case, it is seen that the exhaust valve must be driven by an independent eccentric, and the cost of the engine is thus somewhat increased. This is not a large item, however. The "Greene engine" is an engine fitted with such a valve-motion.

In the accompanying illustration,[1] which exhibits this machine, the valves are seen to be four in number, as in the engines already described. They are flat valves, instead of cylindrical, and are thought by the inventor to be better than the latter, as being easier to refit when worn, and as being less liable to become leaky. The cut-off mechanism consists of a sliding bar, *A*, driven by an eccentric, set to



GREENE VALVE MOTION.

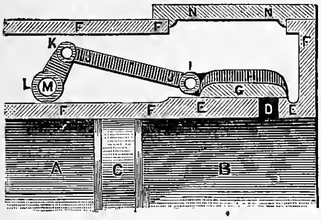
give it motion parallel to the centre line of the cylinder, and with a movement co-incident, as to time, with the motion of the piston; of a pair of "tappets," *C*, *C*, set in this bar

1. Manual of the Steam Engine, Vol. I. p. 102.

and adjustable vertically in such a manner as to engage the rock-shaft arms, *B*, *B*, on the ends of the rock-shafts, *E*, *F*, which rock-shafts are attached to the valve-links inside the steam chest; of a set of springs which hold these tappets up to their work, and in contact with the "gauge-bar" behind the bar, *A*, and out of sight in the drawing. This gauge-bar is adjusted to the proper height, and is varied in position, as the load varies, by the action of the governor which is connected to the gauge-bar by the rod extending up to it at *G*. The exhaust valves are seen below, and are driven by the second eccentric there shown. They are so placed as to thoroughly drain the cylinder of all water carried into it by priming, or produced by cylinder condensation. The eccentric driving these valves is set at right angles to the position of the crank. In consequence of this independence of the two sets of valves, this engine can cut-off at any point in the stroke during a complete half revolution of the crank. This form of engine was invented by a Providence mechanic, Mr. Noble T. Greene, and was patented in the year 1855. Mr. Greene, then of the firm of Thurston, Greene & Co., introduced this engine a few years after the merits of the drop cut-off had been proven by Sickles and Corliss so fully that it was easy to secure a market for new devices of this class; and the introduction of this engine has had much to do with the rapid progress of these more economical kinds of engine.

The form of the engine has been somewhat modified at various times, although its characteristic features have been carefully preserved. The steam valve, as designed by the writer, who, at the time of its first appearance, had an

occasional opportunity to exercise his powers as a designer on this engine, is seen in the next Fig.[1]



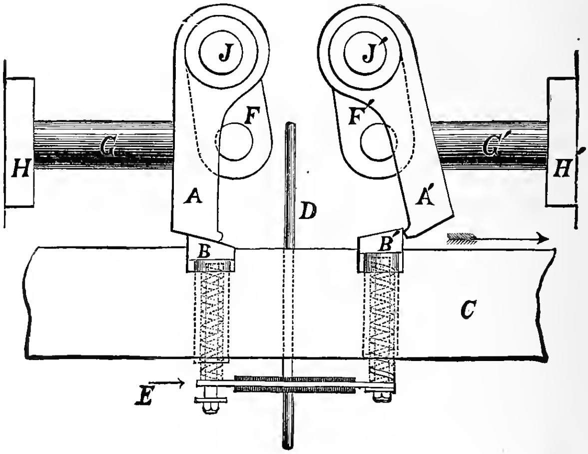
THURSTON'S VALVE.

The valve, *G*, *H*, covering the steam port, *D*, in the cylinder, *A*, *B*, is driven by the rod, *J*, *J*, which is connected to the rock-shaft, *M*, by the arm, *L*, *K*, in such a manner that the line, *K*, *I*, will, when prolonged, intersect the valve-face at its middle point *G*; it is thus so set that the line of action of the link, *K*, *I*, meeting the valve seat directly under the middle of the valve, does not produce any tendency to rock the latter, and thus to cause wear at the edges, or leaks of steam past the valve into the port.

The latest form of the Greene engine, familiar to the writer, is that now constructed by the Providence Steam Engine Co., and shown in the large illustration, page 35. In this engine, the steam valves are connected to the cut-off mechanism, by a set of rods or stems running parallel to their seats, and emerging into the air through stuffing boxes, properly provided with easily set and easy working packing; these valve stems are connected to the rock-shafts, and are driven as in the arrangement already described, very nearly; this design has some advantages over the old, in keeping the working parts, and especially the joints, out of the steam space. The exhaust valves are gridiron slides, set to travel across the line of the cylinder, and driven from

1. Supplied by D. Appleton & Co.

a horizontal rock-shaft, extending forward to the eccentric on the crank-shaft; the governor is a Porter loaded governor, driven by a belt from the main shaft; the cut-off mechanism is illustrated in the last of this series of illustrations.



GREENE TRIP MOTION.

The tappets, *A*, *A*, are carried by the rock-shafts, *J*, *J*, which, in turn, drive the arms, *F*, *F*, and the valves attached to the stems, *G*, *G*, passing through the stuffing boxes, *H*, *H;* the tappets, *B*, *B*, engage these rock-levers, and are adjusted vertically by the governor rod, *D*, and held up against the gauge bar or the rock-lever, as the case may be, by the springs set in the sliding bar. When the speed of the engine is above that for which the engine is set, the governor, acting through the rod, *D*, depresses the tappets, and they do not retain their connection with the rock-lever as long as when at normal speed; when the speed

falls below that fixed by the constructor, the governor rod rises, and the tappets are thus permitted to rise, and to remain in contact with the rock-lever, holding open the steam valve for a longer period than before. The longer the valve is to be kept open, and the farther the steam is to follow, therefore, the wider does the port open to steam. When the tappets travel to the point of cut-off, they swing clear of the rock-levers; the weights, acting together with the pressure of steam upon the valve-stem area, quickly shut the port, and the steam is allowed to expand from that point on to the end of stroke; the higher the tappets are permitted to rise, by the elevation of the gauge-plate, the greater the ratio of expansion; the further they are depressed, the shorter the cut-off. As these engines are constructed, they are capable of cutting off steam anywhere between the beginning and three-quarters stroke; the latter limit is determined by the lead, and by the margin thought necessary to secure certainty of closure of the valve, when tripped, before the piston reaches the end of its stroke. To follow farther would not be likely to be of advantage, as the gain in the mean total pressure would be compensated by the loss due to a retarded exhaust. A safety stop-motion is combined with the governor connection, in such a manner, that if the belt breaks, or is thrown off its pulleys, the steam will be at once shut off, and the danger of accidents, such as sometimes occur with a run-away-engine, is avoided.[1] The valves and seats on the exhaust side are both easily removable, from the outside, have outside connections, and are readily adjusted.

1. A device now usual with detachable valves.

These engines have been, next to those of Corliss, the pioneers in the movement, during the past generation, toward economical working of steam. A double engine upon this plan, substantially, by the firm of Thurston, Gardner & Co., nearly a quarter of a century ago, from designs prepared by Mr. E. D. Leavitt, Jr., for a well-known Eastern mill, had two jacketted cylinders, 26½ inches in diameter, 5 feet stroke of piston, made 50 revolutions per minute, with steam at 100 pounds pressure in the steam chest, and, on trial, worked down to a consumption of 1.98 pounds of coal per horse-power and per hour; the guarantee was 2 pounds. Its fly-wheel, designed by the writer, who was then just out of college, weighed about 20 tons, was fitted up as a mortice gear, with cut hickory teeth, and was given extremely small side clearance; the motion of the engine was so smooth, however, that the presence of the gear was hardly noticeable. This engine was fitted with the gridiron slides, as in the above illustration; they were driven by sliding cams, thus obtaining a rapid opening and closing of the exhaust, and a slow movement while in the intermediate position, with the port either open or closed. This was a remarkably good piece of work for that time, and has not often been excelled since.

This engine, like other engines with drop cut-off valve-motion, is not adapted to such high velocity of rotation as to permit it to work safely at the speed of even the largest and slowest of the two-pole "dynamos;" but, belted to the machine, it will give as great economy, and as great perfection of regulation, as engines of the preceding class. It

is evidently so arranged that no load is thrown upon the governor, and the effort to detach the steam valve is, therefore, not liable to cause any oscillation in the cut-off gear, or variation in the speed of the engine. In all these engines, the difficulty met with by the designer is, not to secure this independence of the governor from the action of the valve-gear, but to prevent the irregularity which comes of the oscillations of the governor itself. The dash-pot attached to the governor, or, sometimes, a friction mechanism, prevents such irregularity.

This valve-gear does not as conveniently adapt itself to the vertical engine as some others, but one of the first engine-cylinders ever designed by the writer, was built with this gear, and was set vertically. It gave perfect satisfaction, if the fact that it was never reported to the shop for repairs, so far as the writer has yet heard, may be taken as evidence of its successful operation.[1]

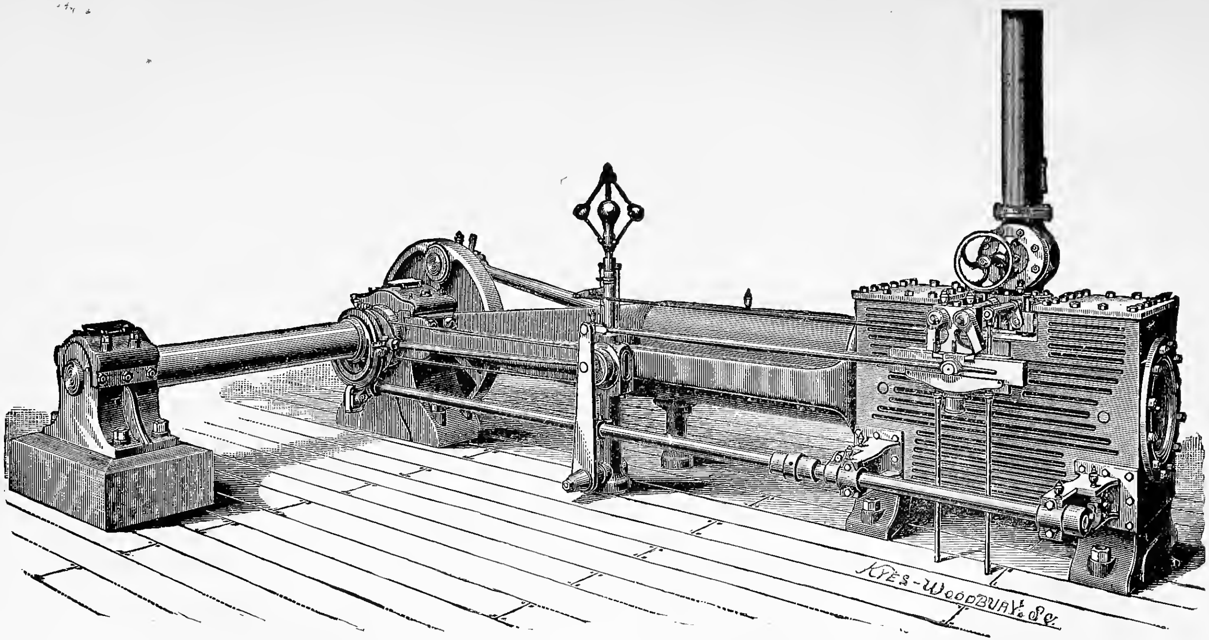
This engine was introduced over a quarter of a century ago, in the face of a strong competition from the Corliss engine—a fact which is, perhaps, the best evidence that it had merit—and by the same methods which Mr. Corliss had proved so effective. Guarantees were given of performance, and forfeitures were provided for in the contract; or else the agreement was accepted to take as payment the saving actually effected in a fixed period of time—usually from two to five years, according to the character of the machine displaced. One of these engines, with which the writer was familiarly acquainted through his indicator, and

1. This engine is still (1895) in use, after 27 years' service, and drives a set of dynamos at South Webster, Mass.

which displaced the rival engine on such a guarantee, has now been in operation 23 years, and is reported to be to-day still in perfect order. The engine referred to above as having given so excellent a performance, was put in under an agreement by which the builders agreed to forfeit $1,000 per ¼ pound that the coal consumption should fall short of the guarantee. The manufacture was interrupted for some years by an injunction secured by Mr. Corliss, after a suit brought by him for infringement, but was recommenced after the expiration of the Corliss patent, and has proved a successful enterprise, notwithstanding the fact that its constructors have depended, apparently, upon the performance of the engine itself for advertisement—a conservative system of doing business which few manufacturers adopt, at present.

All three of the great inventors and introducers of the modern American type of steam engine—Sickles, who brought into use the drop cut-off; Corliss, who gave the stationary engine its now standard form, as well as devised his peculiar valve gear; Greene, who applied the principles of this system of working steam to the plug-tree form of valve gear,—are now (1890) living. Mr. Corliss has acquired wealth, as well as fame; his predecessor and his rival, however, have attained less fame—much less than they are entitled to, and still enjoy all the advantages which poets ascribe to the possession of small means.[1]

1. Sickles and Corliss have since died, leaving behind them a legacy to the world, in their great inventions, the value of which cannot be estimated. Mr. Greene still lives (1896).



THE GREENE ENGINE.

There are other engines belonging to the class here considered—the engines having a detachable cut-off valve closed independently of the motion of the valve-gear,—of which the space proposed for these articles will not permit description. Among these are the Wright engine, constructed by one of the oldest and best known designers in the country; the Brown engine, a machine which has been extensively adopted for driving mills in New England, and is famous for the excellence of its workmanship and finish, as well as for its durability and efficiency; the Fitchburg engine, and others.

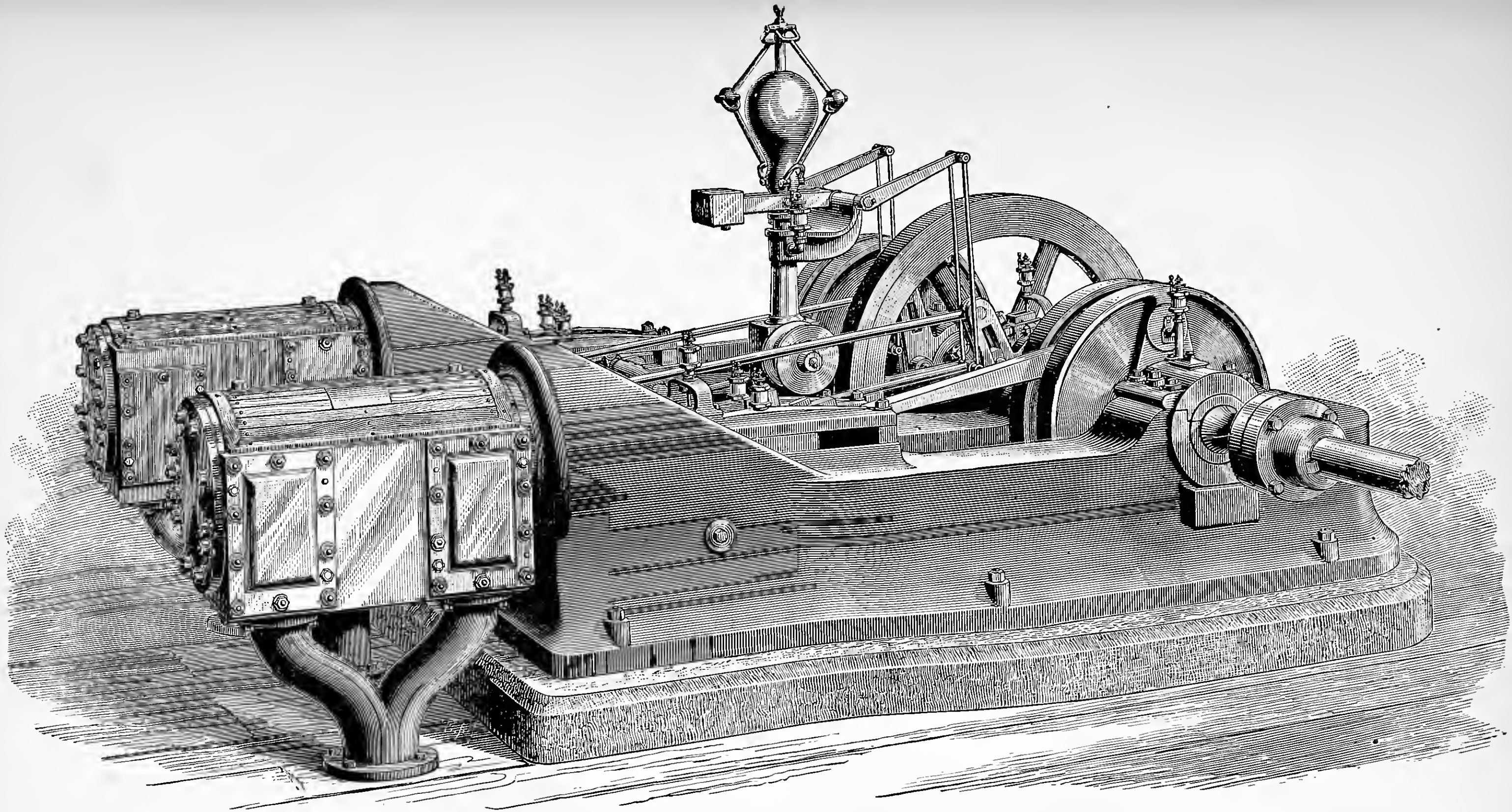
IV.

Engines Capable of Direct Connection.

THE PORTER-ALLEN ENGINE.

THE essentials, in the construction of the steam engine with a view to the economical production of power, as has been seen in the introductory part of this series of articles, include special provision against loss of heat and condensation of steam, at entrance into the steam cylinder, by the action of the metal surfaces to which it is exposed on all sides at the beginning of the stroke. One of the methods of securing this economy in the working of steam, has been stated to be the driving of the engine up to the highest safe velocity of piston, and giving it a maximum speed of rotation. The time allowed for condensation of each charge, and for the necessary change of temperature preceding such condensation, is thus reduced, and the amount of steam condensed being thus made a minimum, in any given time, the percentage of loss of the increased quantity of steam worked off by the engine becomes the least possible. The engine does a greater amount of work, and is subject to less loss. Thus the work to be done being fixed, it is done by a smaller, and, other things being equal, a less costly engine, and at the same by a more economical machine.

Although this seems a sufficiently simple and axiomatic philosophy, and although the general tendency of practice in steam engineering had been plainly in this direction for



Pair of Porter-Allen Engines.

many years, these points had not, up to a comparatively recent time, been recognized by constructing engineers, and their progress had been slow and difficult. The older firms who were engaged in the building of what were then called "expansion engines," were the first to detect this movement and its cause, and they led off, in a very conservative way, toward the construction of faster engines. The firms already mentioned as leading in the movement toward correct practice, came up to speeds far ahead of those common among other makers, and secured an advantage that was sufficient to prove unmistakably that they were in the right track. They did not, however, modify their designs in any great degree, with a view to adapting them to very high speeds. Their valve-gears were not of a kind well fitted to high speed of rotation; the builders, were themselves disinclined to accept the risks undeniably attendant upon rapid change in this direction, and the public to whom they looked for a market were not educated up to such a point as would make it safe to attempt to go on very rapidly. A rather slow engine, with its comparative immunity from risk of serious accident in case any little derangement should occur, and with its greater durability under the ordinary conditions of use, was, by the great majority of designers, builders, and steam users, thought a far better investment than a fast engine, however well adapted to the radical illustration of a very interesting, but apparently impracticable, philosophy.

The first man to take up this matter with a will, and with a faith and a determination that were equal to the task, was Mr. Charles T. Porter, a young lawyer turned

engineer, and Mr. John F. Allen, when the writer first knew him, a skillful mechanic, who was showing the natural bent of a real inventor, in the production of new devices, while engaged in the management of some of the best engines of 30 years ago. The valve-gear of the Porter-Allen engine is the invention of Mr. Allen, and its governor and general arrangement are due to Mr. Porter. It was Mr. Porter, also, who, by his courage, persistence, skill in business, and general good sense and management, finally, after years of struggle to secure good construction and workmanship, brought the engine into use in spite of every discouragement, whether due to circumstances, to direct opposition of competitors, or to public sentiment in favor of conservatism.

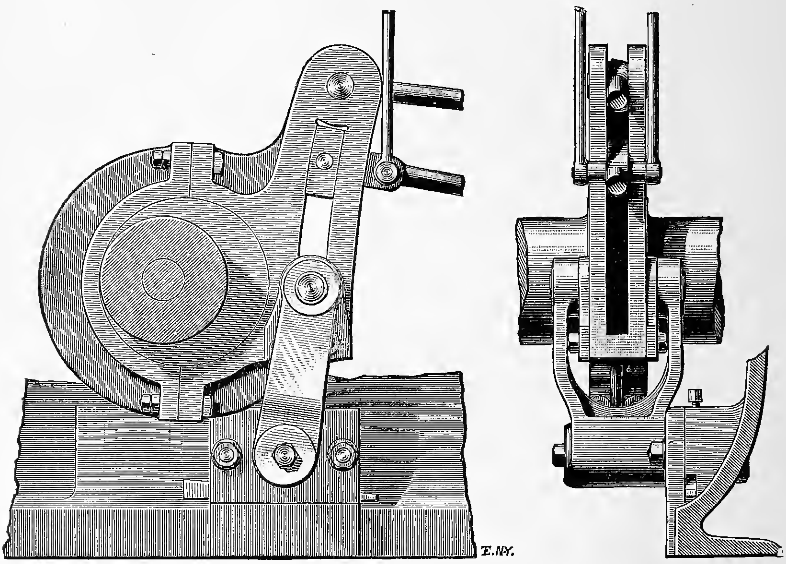
There are some interesting problems which present themselves to the engineer who attempts to design an engine to be operated at very high speed—problems which are by no means easy of solution, except to the boldest of innovators. One of these points of difficulty has already been considered. When the speed of revolution is increased, it is evident that a limit must sooner or later be attained at which the drop cut-off must be exchanged for some "positive motion" gear. But the various forms of such gearing familiar to engineers when Messrs. Porter and Allen became acquainted with each other, years ago, the still common three-ported valve, such as is used on locomotives, the Meyer valve with its cut-off valve on the back of the main valve, and kindred devices, were not adapted to the conditions sought by the engineer looking for a good system of expansion. They were simple and inexpensive, and could be used at any practicable speed of engine; but they did not always give a

satisfactory distribution of steam. They usually produced a retarded steam supply, a "throttling" of the steam at the point of cut-off, which was not at all such as would satisfy the engineer familiar with the prompt action, and the "sharp corners" of the indicator diagram from the class of engine then taking the market. The dependence of the several parts of the motion upon each other was another objection to these devices, and the load which they threw upon the governor was a fatal defect, as the governor was then arranged and connected. Mr. Allen's invention placed in the hands of Mr. Porter just the device that he needed to carry out his idea of a fast engine.

This arrangement consists of a single eccentric driving a link motion to operate the steam valve and to work the exhaust at the same time. The link is controlled by a Porter governor, and is so connected and driven that the gear may be readily and quickly adjusted by the governor to any desired point of cut-off.

The eccentric and link are shown in the next illustration. The eccentric is set on the shaft in such a position, that its motion is co-incident with that of the crank. The link is a slotted curved arm, forming one piece with the eccentric strap, pivoted at the middle on trunnions sustained by an arm rocking about a pin set in the bed of the engine. The upper end of the link carries a pin, from which a rod leads off to the exhaust, which is driven without variable connections. The link-block is fitted to work in the slot of the link, from the end nearest the exhaust rod pin, down to the point opposite the pivotal point at which the trunnions are set. When it is at the upper end, the throw of the valve

is a maximum; when at the lower point, it is a minimum. As the link-block is moved up and down in the slot, the motion of the valve is varied, and the ratio of expansion correspondingly altered. By an ingenious adjustment of a still more ingenious form of valve-motion, it is thus possible



THE ALLEN LINK.

to obtain a valve movement of perfect precision at all speeds, and on both the forward and the backward stroke, with a quicker closing action, as the cut-off is later. The steam is allowed to enter the cylinder, at nearly boiler pressure, almost up to the point of cut-off, and the expansion line is a smooth curve very nearly from the junction with the steam line.

This form of indicator diagram has been usually considered peculiar to the class of engine described in the preceding articles. In this case, the diagram is nearly as sharp in the corners as those from a drop cut-off engine. The range of expansion is from the beginning of the stroke to about five-eighths.

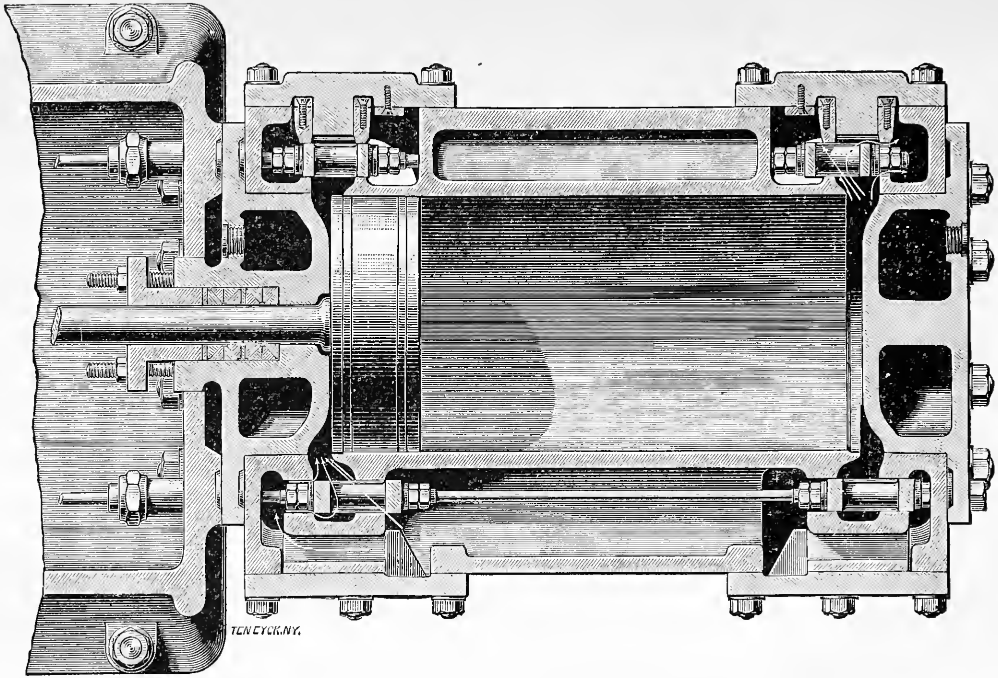
There are four valves, as shown in the next Fig., which is a section through the steam cylinder showing valve, ports, and general construction. The two valves at the upper side of the cylinder are the steam valves; the lower are the exhaust valves. This section is, however, horizontal, the valves being set on their edges at either side of the cylinder. The exhaust valves are so placed as to drain the cylinder of any water that may have entered with the steam, or may have been produced by internal condensation. Both sets of valves are so made, and set, as to be well balanced, and so as to be capable of having the wear taken up when it occurs. All these valves are provided with pressure-plates, which are adjustable by hand, to make them steam tight, as well as to secure a perfect balance. Each valve is placed in a separate valve-chest, and can be independently adjusted. Each valve opens four ports; each is so set, that it is actuated by a rod in the line of its own centre; and all are thus rendered but little liable to either wear or leakage.

The rock-shaft arm on the intermediate rock-shaft, seen in the large Fig. between the eccentric and the steam valve stem, assists in securing the quick opening and closing motion essential to a satisfactory distribution of the steam.

The features which have now been described, are not

necessarily distinctive of a "high speed engine." A positive motion valve-gear, and a good steam distribution, are desirable in such engines, and the first point is, in fast running machines, an essential requisite; but the Allen engine, so far as it has been described, may be as well considered a slow as a fast engine. There are some details, to which we are now to turn our attention, which are essentially and peculiarly characteristic of the class to which this machine is assigned. Among these points are the strength and rigidity of parts which distinguish such engines; the great nicety of fitting; the excellence of all material in every part exposed to the straining action of inertia, and the minor but yet important modifications of details to adapt them to service in a machine, in which the slightest play in joints or bearings will be certain to make trouble. The bed is of peculiar design and is enormously stiff and solid, especially in those parts which take the stresses of the reciprocating pieces. It is broad and deep, with the line of thrust of piston rod carried close to its surface between the guides, and with a box form which gives great resistance to forces tending to twist it.

The steam cylinder is secured to the bed by the end, a construction adopted by Corliss many years ago, and one which gives all desirable strength, with freedom from those strains which come of connection of two large masses at different and constantly varying temperatures. The whole of its exposed surface is covered with lagging to prevent loss of heat by radiation. The main journal boxes are made in four pieces, and are set up by adjustable wedges, so set as to avoid the springing of the shaft that is some-



Steam Cylinder (Section).

times found to occur with a less effective arrangement. The main-shaft journals, and the journals of the crank-pins, are made with especial care, skillfully ground to size and form, and nicely finished before the engine is assembled. The pin is always of "mild" steel, carefully case-hardened to give it a surface that will wear well and will not "cut."

The provisions for lubrication in such engines are not the least important of its details. The engine presents some neat devices in this respect which we have not space to describe.

One of the most remarkable and interesting of the features, which especially adapt this engine to great speed of rotation, and one, the developement of which, in its theory, as well as in practice, is due to Mr. Porter, is a peculiar adjustment of weight of moving parts to the equalization of stresses on the line of journals between the piston and the crank-shaft. When the steam is allowed to follow the piston only to some point early in the stroke, the ratio of expansion being made, as is usual, between three and five, the rapid fall of pressure, during expansion and up to the end of the stroke, causes a very great variation in the effort exerted upon the crank-pin and other journals. As the maximum pressure occurs when the crank is passing the centres, and while the work done usefully is, in consequence of the slight travel of the piston, very little, and as, at the same time, the considerable movement of the pin under this pressure causes a considerable loss of work by friction, and as it is advisable to secure a uniform effort producing rotation, it is evident that it is desirable to find a method, if possible, of equalizing the pressure throughout the stroke without sacri-

ficing the advantages of expanding the steam. The action of inertia in the moving parts is made by Mr. Porter the means of securing this result.

At the beginning of the stroke, the inertia of the piston, its rod, the crosshead, and to a certain extent the connecting rod, all reciprocating parts, causes them to offer a certain resistance to the accelerated motion which they are compelled to take up. This resistance becomes less and less up to zero at half stroke, the point at which their velocity is a maximum. Passing this point, they are rapidly retarded, and this same property of inertia causes them to offer a resistance to retardation, which resistance now is felt as an impelling force at the crank-pin. Thus, the effect of the presence of these heavy masses in the line of connection, produces a reduction of pressure upon the pin at the commencement, and an increase of pressure at the end of stroke. But, in consequence of the varying action of the steam producing an excess of pressure at the beginning, and a deficiency of pressure at the end of stroke, we may combine these two effects, and the result is a comparatively uniform load upon the crank-pin throughout the stroke.

This compensation is capable of being, in many cases, very nicely adjusted by properly proportioning the weight of the reciprocating parts. As engines are usually proportioned with a view to strength of parts simply, the piston, crossheads, and rods are too light to be of much service in this way. Mr. Porter adopted the plan of making his piston and crosshead of such weight that the equalization of pressures should be the most complete possible, and this involved making them decidedly heavier than they are made

in common practice, even when his engines were driven up to a speed which had never been before attempted in stationary engine practice. It is evident, however, that at some higher speed, the weights of these parts, as proportioned for strength simply, would be sufficient to give this desirable adjustment of the load on the crank-pin. There is no reason to suppose that this, which the writer has called natural speed of the steam engine, may not be at some future time attained.

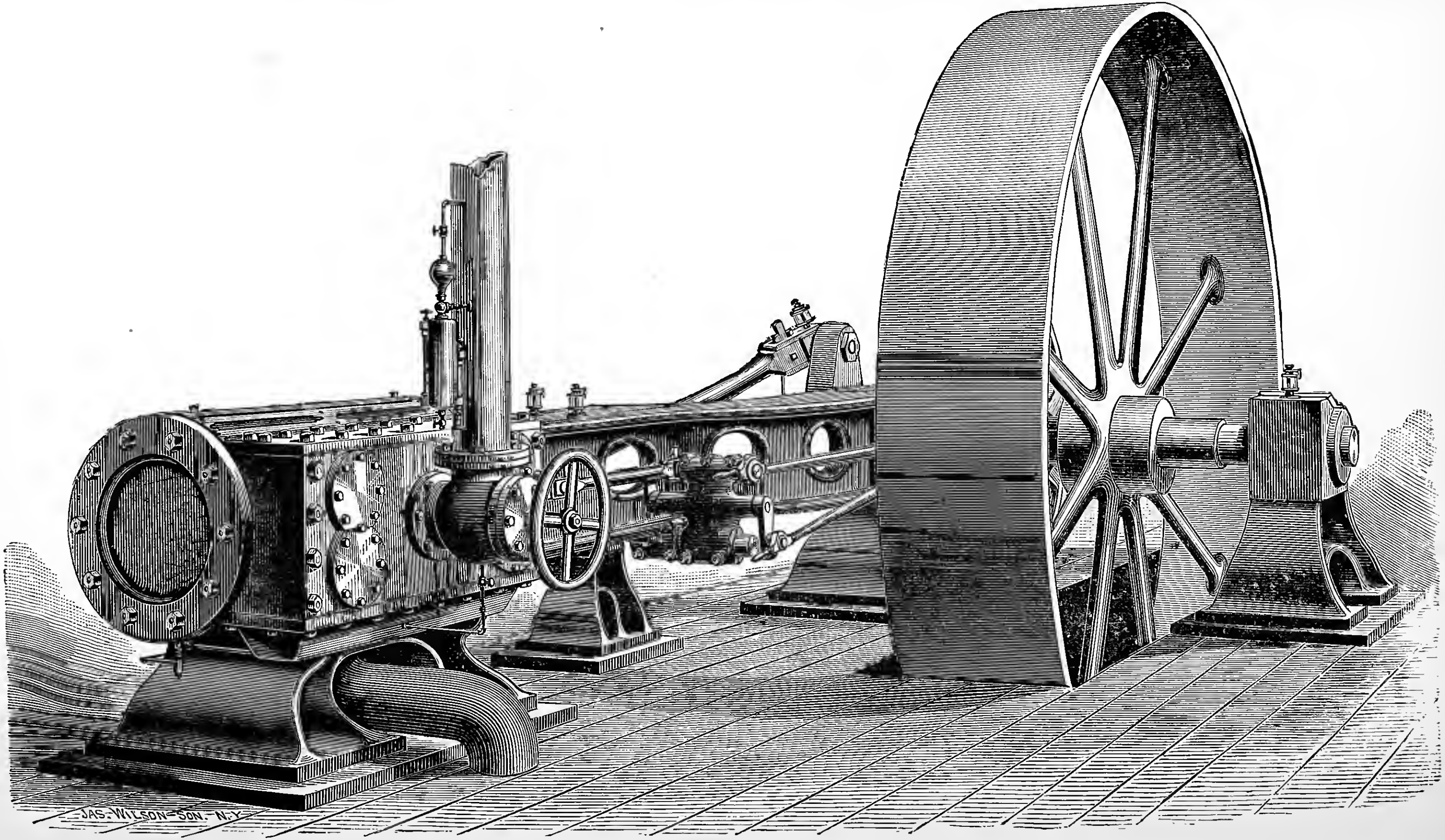
An interesting fact in this connection, is that Mr. Porter, although not professionally a mathematician, or educated as an engineer, first worked out the relations of these forces by a simple process, and applied his results to his practice, and that, subsequently, at his request, a distinguished mathematician, Dr. Barnard, President of Columbia College, attacked the problem by the methods of the higher analysis, and revealed the laws involved, and verified completely the work of the engineer. (See Man. St. Engine, Vol. II. § 116.)

The Compound Condensing Porter-Allen Engine, having cylinders 24 inches and 46 inches diameter, by 42″ stroke of pistons, makes 120 revolutions per minute, at which speed it is rated at about 1,100-horse-power capacity.

On the main shaft is carried the armature of an 800-kilowatt dynamo. The same general arrangement is followed in all sizes where this type of engine is connected directly to an electric generator. An advantage of the higher speeds, where direct driving is adopted, is the reduced first cost of the dynamo. The Porter-Allen engine is built to run at various speeds, from 360 revolutions per minute for 100 horse-power to 120 revolutions per minute for 1,500 horse-power.

Engines of this class have many advantages, consequent upon their high speed; they are, other things being equal, more economical in the use of steam; they can be given a very much smaller fly-wheel; they have, in consequence of the enormously reduced weight of wheel, less friction; they are more easily held to their speed by the governor; they are less subject to variation of speed between beginning and end of any one stroke; and they are usually less troublesome and expensive to connect to the load than slow running engines. These advantages are common to all classes of engines, as they are driven up to high speeds; the class here considered is simply better fitted to realize these advantages than the older forms of engines, because they are especially designed for high speed. The objection to the "high speed engine," is the increased risk of wear, and of accident due to their rapid motion, and especially the risk, that when accidents do occur, as they will now and then in the best regulated establishments, they may be vastly more serious than with engines working at ordinary speeds. The object of the precautions which are taken by builders of fast engines, are all directed to meeting this contingency, and to making their machines safe against accident. These precautions are seen to be the strengthening, and especially the stiffening, of all the parts exposed to the stresses due to the action of inertia in the reciprocating pieces; the adjustment of all parts to each other in such a manner as to avoid spring; the use of the best material; an effective system of lubrication; and the securing of the most perfect workmanship.

Watt once congratulated himself that he was able to get



Buckeye Automatic Engine.

a steam cylinder that only lacked three-eighths of an inch of being truly cylindrical; the builder of the "high speed engine" of to-day works to the thousandth of an inch, in longitudinal measurements, and gets his cylindrical journals exact to the twenty thousandth, perhaps to the fifty thousandth of an inch, a quantity which can be detected by a good workman. The contrast illustrates well the progress of a century in accuracy of workmanship where nicety is required. Such nicety, only, can make a fast running engine safe; such accuracy *does* make it safe, and such engines now do their work uninterruptedly, year in and year out, and are found to require no more than that ordinary care which all engines are expected to receive.

A Porter-Allen engine, from the "Southwark Foundry," supplied power to the Weston, Edison, and the Thomson-Houston Electric Light Companies at the Railway Exhibition at Chicago, May and June, 1883.

THE "BUCKEYE" ENGINE.

THE engine last described was a long time alone in the field as a "high-speed engine." The principle represented by its designers was recognized as correct by every intelligent engineer, and it was admitted that the fast engine, other things being equal, would prove the most economical in its expenditure of heat, as well as in its efficiency as a machine subject to friction. But builders were not able to bring themselves to accept what seemed to them the risks incident to high speeds. The pioneer in this new field was not altogether successful for a time, and it seemed to be

certain at one time, that the engine, despite the pluck, the persistence, and the skill of its indefatigable promoter, must retire from the market. But no discouragement could quite destroy confidence in this engine, which had become the embodiment of the most recent phase of progress. Gradually, one difficulty after another was overcome; parts were strengthened and given satisfactory proportions; the materials were improved and the workmanship of the machine was made as nearly perfect as the best tools, handled by the best workmen, could make it. A little gain was seen each year, and, after a time, it was seen that the new class of steam engine had "come to stay."

One of the first engines to come into the field after this period of doubt had closed was built by an enterprising firm of Western manufacturers. This was the "BUCKEYE ENGINE," designed by Mr. J. W. Thompson, and built by the Buckeye Engine Co., at Salem, Ohio. The engine did not start as a radical competitor of the pioneer engine; but it was from the beginning, a moderately high-speed engine. It was fitted with a positive motion "automatic" valve-gear and a balanced valve, and had a stability and an excellence of workmanship that made it safe at fast speeds; while the peculiarities of its construction were such as gave it a very high place as an economical machine. It was capable of meeting in competition the best engines of the day.

The form given the larger sizes of this engine is seen in the preceding Fig. The general arrangement is not essentially different from that of the Corliss engine, which has been described in earlier articles.

The cylinder is carried on a pedestal, as is the latter;

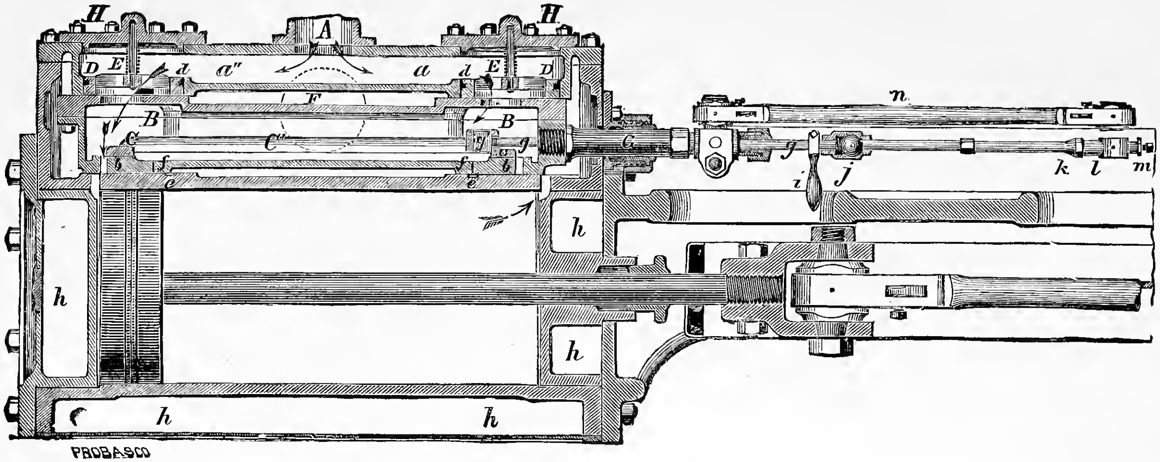
the frame consists of a girder uniting the cylinder and the main pillow block and carrying the guides; the crank-shaft end is carried by another pillow block. The main frame is, however, supported by a strut which is now usually seen in other engines, and which takes the load tending to spring the girder under the guides. The construction of the cylinder, and the arrangement of the valves, is shown in the next Fig.

The live steam is taken into the steam-chest at *A*, passes through the passage, *a*, *a*, through the openings, *D*, *D*, into the box-shaped valve, *B*, *B*, and thence through the ports, *b*, *b*, into the cylinder, as the ports in the cylinder are alternately brought opposite those in the valve. The cut-off valve is formed of two sliding plates, *C*, *c*, connected by rods, C', and sliding on seats formed on the inner, or working, side of the main valve, so as to cover the main steam ports alternately, and at times which are determinable by the governor. The stem, *g*, driving this valve, passes through the main valve stem, which is made hollow for that purpose. The cut shows the steam entering the cylinder at the left, and the cut-off valve just beginning to slide over the port, while the exhaust is taking place at the right, *past the end of the main valve*, through the chest, and around to the exhaust pipe seen partly dotted at *F*. At *e*, *e*, are seen two "relief chambers," which receive live steam from the steam valve through holes, *f*, *f*, and thus balance the valve at a time when the pressure on the seat caused by the then excessive area of the balance openings, *D*, *d* (which openings must be made sufficient in area to produce a slight pressure of the valve on its seat when the tendency to lift

the valve from its seat is greatest), is overbalanced. These holes only fill when this relief is needed. The equilibrium rings, *D*, *d*, seal the joint between the valve and the diaphragm separating the steam-chest, *a*, *a*, from the exhaust-chest *F*.

The governor is of a type that has not been seen in the engines previously described. It is shown in the following illustration, page 68.

In the common "fly-ball governor," the two balls revolve about a vertical spindle, to which they are attached by a pair of arms in such a manner that they may take any position that the resultant action of gravity, centrifugal force, and the pull on the supporting arms may give them. A defect common to all governors of this class is that the force tending to pull the balls downward is perfectly uniform. Gravity never changes at any one place. The position taken by the balls, at any fixed speed of engine, is always the same; the connection of the balls with the regulating mechanism, is one which always preserves a fixed relation between the position of the governor balls and the position of the regulating apparatus. Thus it happens that the engine can never be kept precisely at speed, unless the speed is such as will give the governor exactly its normal position and, at the same time, such that the valves shall supply just the normal quantity of steam to the engine. With reduced steam pressure, the engine drops to a slightly lower speed, and runs at that speed instead of the proper number of revolutions; when the load decreases, the engine runs at a little higher speed than is intended; and no method of attaching that form of governor can give absolutely uni-

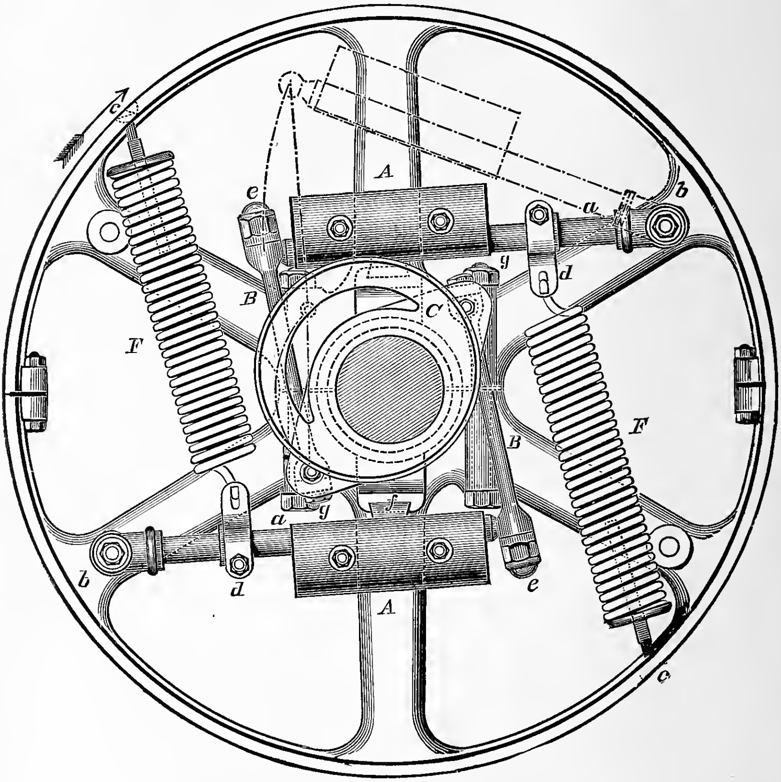


SECTION OF CYLINDER AND VALVES.

form speed. If, however, we can substitute for the action of gravity, a force which can be made to vary with change in the position of the balls, in such a way that the variation in the opening of the throttle, or in position of the point of cut-off, shall go on until the engine comes to speed, irrespective of all other conditions, we shall have what is known as an "isochronous" governor, and shall be able to get the correct speed, whatever changes occur in steam pressure or in load, provided that there is steam enough to drive the load at speed with the least expansion for which the engine is designed. Such an adjustment can be made by substituting the tension of a spring, properly set, for the action of gravity. The form of governor here illustrated is, or can be made to be, of this class. It simply requires that the spring tension shall be given a certain easily determined relation to the effort of centrifugal force.

A governor of this character, when well made and adjusted, will open the throttle valve, or will increase the ratio of expansion, as the steam pressure diminishes or as the load is increased, and will continue to move in the proper direction, indefinitely, or until the machine comes to speed, or until the engine is doing all that it can do. In the governor here used, two levers are set on either side the crankshaft, in a frame or a pulley to which they are pivoted at *b*, *b*. These rods carry weights, *A*, *A*, which may be adjusted to any desired position by means of the bolts seen in the cut. The outer end of each rod is linked to the loose eccentric, *C*, *C*, by the rods, *B*, *B*, and is controlled by the springs, *F*, *F*, which resist the effort of centrifugal force tending to throw the weights outward. As the weights

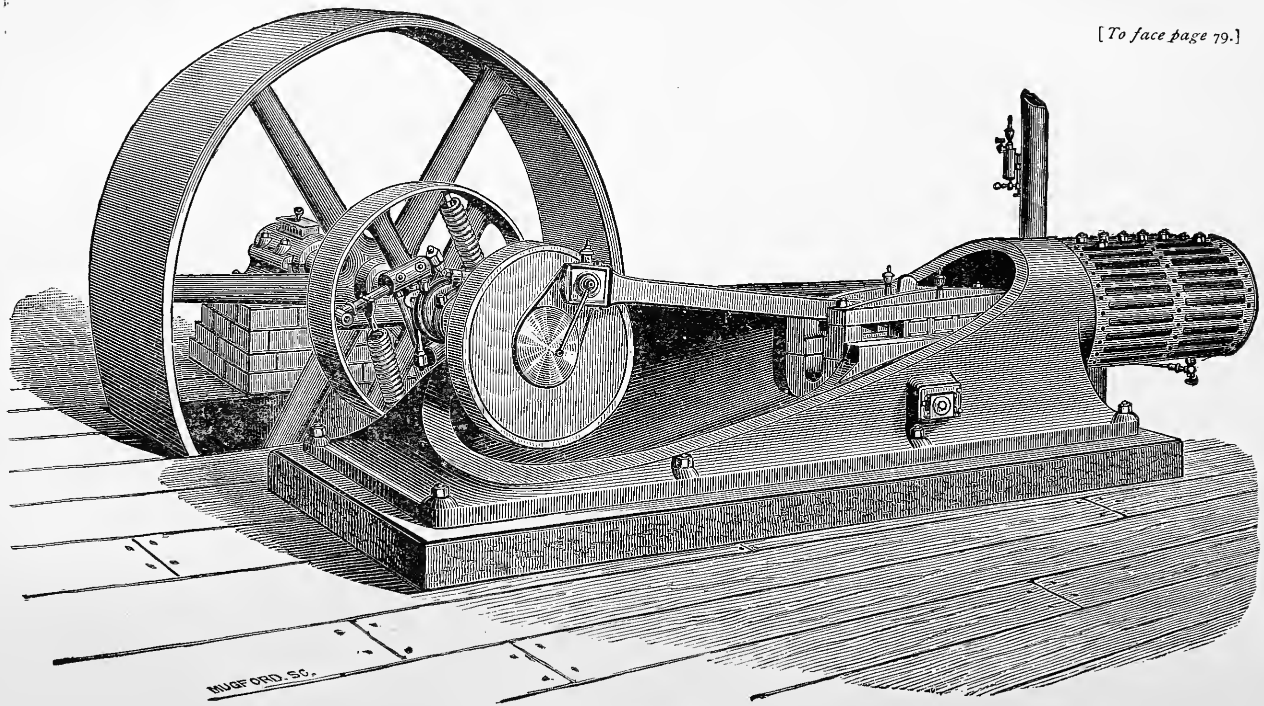
swing outward or inward, as the one or the other of the two opposing forces predominates, the eccentric is turned on the shaft in such a manner as to give the valves that motion which is necessary to produce the proper distribution of steam



Governor.

to bring the engine to its speed. The adjustment of this regulator to its work is easily obtained by the shifting of the weights along the levers, or by increasing or diminishing their amount, as is found necessary.

[To face page 79.]



BUCKEYE STANDARD ENGINE.

This governor is adjusted for an engine moving in the direction of the arrow. To adapt it to an opposite motion, the pins, *b*, *b*, are shifted to the other set of arms which are shown having bosses for their reception. Wooden buffers check the governor at the extremity of its range of motion.

The range of expansion, as determined by the governor in this engine, is from the beginning up to two-thirds stroke.

The engine has many interesting peculiarities of construction, in its details, which space will not permit us to consider.

A licensed engineering company formerly building this style of engine made a form of bed which is somewhat similar to that designed by the makers of the Porter-Allen engine, but which is particularly solid and graceful in appearance. It is seen on the opposite page.* This firm, as well as the original makers of engines built under Thompson's patents, thus tried to secure in their engines great weight in the parts in which solidity is important, such large area of bearing surfaces as is essential in these engines, moderately high-speed of piston and of rotation, a steam pressure, usually of about 80 pounds per square inch, and adopt a ratio of expansion for their non-condensing engines, of from four to five. Their table of powers of their standard sizes is based upon estimates for steam at 80 pounds and a cut-off at one-fourth. In construction, these engines are carefully made with all joints

* The first designer to carry the line of the steam cylinder along the surface of a "box-bed," and thus to secure maximum vertical and horizontal stiffness in this manner, so far as the knowledge of the writer extends, was Dr. E. D. Leavitt, Jr., who made such an arrangement in engines, in the design of which the writer assisted, as early as 1860.

scraped, and all pins, and all journals also, ground with scrupulous care.

The method of regulation is, as has been seen, quite different from that practiced by the older standard makers. It is subject to the objection, that as the regulator has thrown upon it the duty of altering the position of the eccentric, the load so brought upon it may make it less sensitive and less effective in regulating the speed. This conclusion, which is that usually held by the older engineers in the profession, seems to be contrary to the fact; although, when comparing the older kinds of engines, it is fully sustained by the superior regulation of the engines of the "automatic" class. The fact, now familiar to every engineer accustomed to the management of electric lighting machinery, that engines having regulators of the class to which that under consideration belongs are capable of giving a good regulation, even when directly connected to the dynamo, is sufficient proof that such a system of regulation may be able to do perfectly satisfactory work. The frictional resistance of the system, while in motion, is not a matter of importance; as in any system in movement, and subject to jar, the friction is practically eliminated and every part assumes the position that it would take in a similar system free from friction. The action of the resistance of the valve, so far as it is transmitted to the regulator, probably acts to hold the regulator fast during the period of its action, leaving it free to move into any new position, corresponding to the speed of the engine at the instant, without hindrance during the remainder of the time.

All of these fast-running engines will be seen to have

shorter strokes of piston than is customary with the earlier types. One reason which has guided their designers to this proportion is that the loss by internal condensation becomes less as the steam is given less time to discharge its heat, and hence high-speed of rotation and short strokes are adopted. The best proportion of stroke to diameter of piston, the number of revolutions in the unit of time being fixed, is easily ascertained by a very simple investigation. It is found to be two to one. This is about the proportion generally adopted in these engines. Many engines are, however, given a ratio of 1 1-2 to 1. The shorter stroke has the great additional advantage, the speed of piston being the same, of giving a less costly engine to build. The proportion is sometimes dictated partly by the character of the work to be done; thus, in driving the dynamo directly, the velocity of rotation must be very great and a short stroke becomes advisable—the shorter as the speed is higher. In such cases, therefore, engines are often made with even shorter strokes than considerations of "efficiency" alone, would dictate.

Reviewing the construction of this engine, it is seen that it is distinguished from those which have been already described, by its peculiar balanced valve which can be proportioned to take any desired part of the steam pressure, leaving, if properly adjusted, just enough on the valve to hold it with certainty to its seat and to secure a little wear to give bearing and fit between valve and seat, that this valve is arranged to take steam through, and to deliver steam outside, the shell; that it has a system of perfectly flat wearing surfaces, and a positive movement of in-

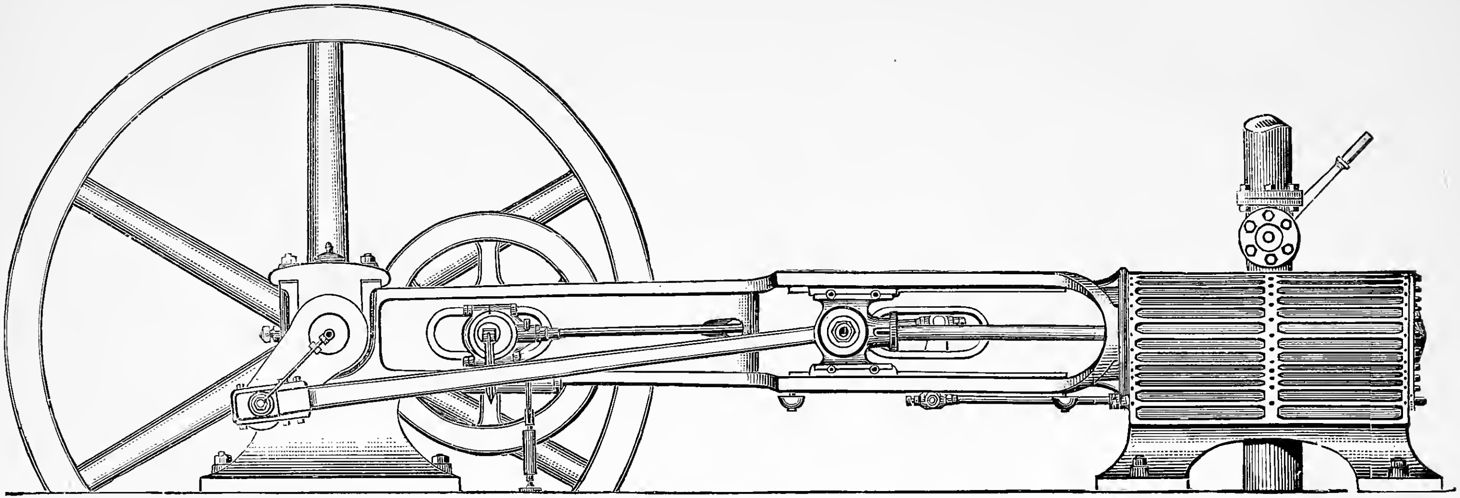
variable extent, and thus is not liable to the formation of shoulders on seat or valve; that its clearance is so small that it is easy to counteract any ill effect, ordinarily due to that cause, by moderate compression; that it has two ports and thus possesses such advantages as may be claimed for that arrangement; that the governor is driven by a positive connection with the shaft on which it is set; that, as the cut-off is adjusted by the motion of an eccentric, the ratio of expansion is the same at both ends of the cylinder and that it possesses the advantage, common to all engines having a positive motion valve-gear, of being unrestricted in speed.

Many of these engines are already in use driving electric lighting machinery.

THE CUMMER ENGINE.

ALL of the class of engines now under consideration have been seen to differ radically from the engines previously described (as not well fitted for direct connection to the dynamo), and to have a number of characteristic points in common which especially fit them for use in direct connection. This latter class of engines, however, exhibit some differences among themselves which are important and very interesting to the engineer and the user of steam power.

The engine last described will have been seen to differ, in a very notable way, from that which immediately preceded it. The latter had a system of valves that differed from the former no less radically than did its system of regulation. We have now to study an engine which re-



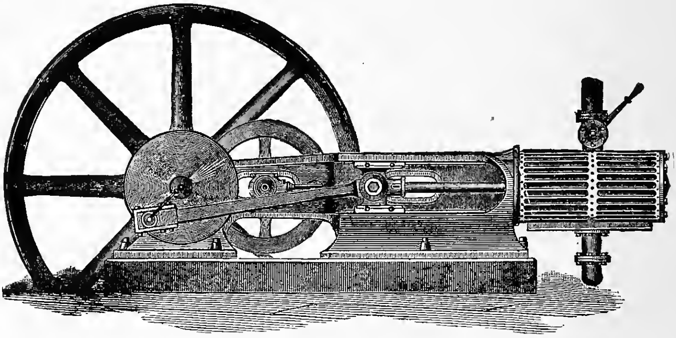
The Cummer Engine. "C"

sembles the last in its general features—the use of a cut-off valve riding on a seat formed upon or in the single main valve, a system original in principle with Meyer, an engineer well-known, years ago, in Europe, and the use of the peculiar form of governor which adapts itself to a position on a horizontal or on an upright shaft with equal facility. This engine, however, has some curiously interesting and ingeniously contrived points of construction which, as well as its performance, make it well worthy of attention. This, the "Cummer Engine," is illustrated in the engravings to be described below.

The builders of this machine make a number of different forms of engine, using various kinds of valve-gear and different forms of regulator and of engine frame; but the style with which we are here principally concerned is that which is best adapted to driving a load at high speed with great economy and with the most perfect regularity.

The general form of the engine, as shown in the Fig., on page 74, is very similar to that of engines already described. It has the "girder" frame, or bed, is well supported at each end, has a firm and substantial connection in the line of thrust and pull between cylinder and crank-shaft, and provisions for lubrication especially fitted to give safety at high rates of speed. A modified form of bed is seen in the next illustration, in which one of the engines designed for the highest safe speeds is shown. In this engine, the frame is made with a pedestal cast upon it directly under the guides and extending under the whole length traveled by the crosshead, thus giving absolute stability at the point at which cross strains are most severe and most productive of injury.

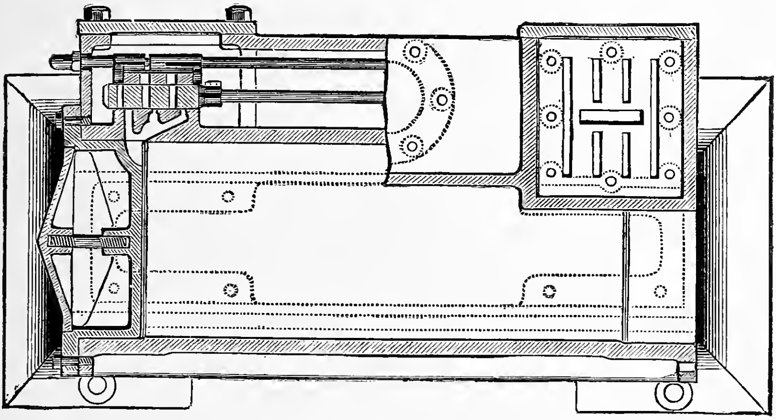
The cylinder overhangs, unsupported, at the back end of the frame. No support is there needed, however, as no appreciable vertical stress occurs there. This engine has the same valve and gear, and the same form of governor as is used in the preceding style of machine. In this latter form of engine, the crank is replaced by a disc, an arrangement which enables the builder to effect a more perfect balancing of the reciprocating parts than can well be obtained with the ordinary form of crank. The rigidity of this form of engine is seen to be as essential a feature as in those which have been previously described. The box girder gives this stiffness in a very satisfactory manner.



THE CUMMER ENGINE. "B."

The main guides are flat, and are fitted with removable faces which can be readily repaired or replaced, when worn or "cut," at small cost of time and money. The crosshead is a compact, strong casting, having bearing surfaces extending well out under the pin, and under the piston-rod socket, as well, and it is therefore not likely to cause those awkward accidents, due to springing the piston rod at this connec-

tion, which have proved so costly in less well designed engines. The gibs which take the wear are removable and adjustable. The main bearing is fitted with four-part boxes of babbitted cast iron, the side pieces so arranged that they may be set out to a bearing as they wear. All the details are in accordance with standard practice in this class of engines, and description is not called for here. It may be safely assumed that this is the case in any successful engine, as good workmanship, the best materials, and a strong system of connections, are essential pre-requisites to even the beginning of success.



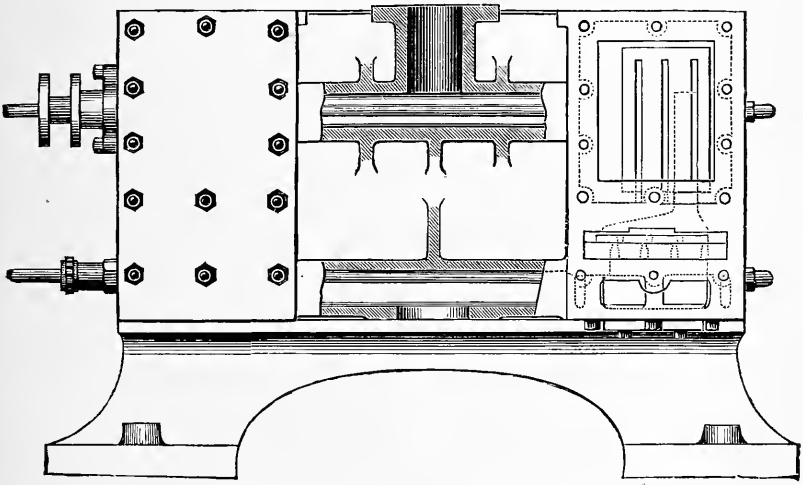
CYLINDER; STEAM VALVES.

The valves and the valve-gear of the Cummer engine, as has been stated, belong to the "Meyer system" and consist of a main valve with the cut-off valve riding on the back of the main. There is this difference, however, between the gear of this engine and others of the same general system: that here we find a separate system of exhaust

valves which are worked independently of the steam valves, and thus leave the induction and eduction motions entirely free to be adjusted as the designer, the constructor, and the user, may desire. The preceding engraving shows the disposition of the valves in the cylinder casting, and the larger cuts exhibit the method of driving them. The section of the cylinder, above, is made horizontally through the steam valve chest, and shows the main valve in section, with the cut-off valve riding upon it. At the left is a section so made as to exhibit the exhaust valve seat. This is made removable. It will be noticed that the valves are of what the engineer calls the "gridiron" pattern. They are so made, with their several ports, to obtain a free opening with small movement and reduced friction of the valve. The writer has found this device a decidedly advantageous one, and it has been used by some of the most successful designing engineers of his acquaintance. The more numerous the ports, the less the travel required for the valve, the smaller the steam chest space demanded, and the less the load on valve-gear and governor, usually.

The next illustration represents the same parts of the engine as seen from the side, with valve-chest bonnet removed at one end, and a section made opposite the supply pipe to show the passages and valve-rods. These rods are driven by the main eccentric, the steam valves directly, and the exhaust through a rock-shaft. The cut-off valve is driven by a separate eccentric, as in the preceding form of engine, and this eccentric, like the preceding, is adjustable in position on the shaft by the governor. The engine is thus made "automatic" in its adjustment of the point of

cut-off, and in regulation. Separate valves are seen at each end of the cylinder, and the "clearance" and "dead space" is thus reduced to a minimum. This last provision makes it possible to "cushion" the exhaust steam up to boiler pressure on the return stroke, and thus to secure a minimum waste by condensation on the opening of the steam valve for the succeeding stroke. Cushioning is not here limited by the steam side. The construction of the connecting rod, and the method of connection, are such that the wear of jour-



CYLINDER; ELEVATION AND SECTION.

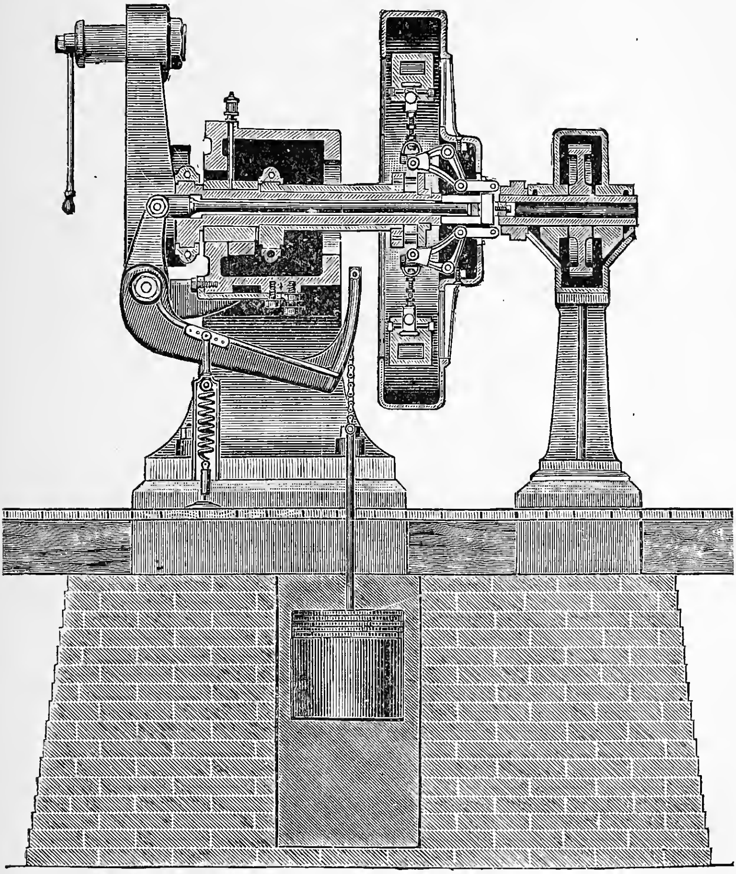
nals and bearings may be taken up, in any case, without altering, to any observable extent, the position of the piston in the cylinder, and this permits small cylinder clearance, also. For the reason above given, the port spaces are made no larger than is necessary.

A comparison of this engine with others of its class will

exhibit one very peculiar feature, in which this engine stood entirely alone. The governor is carried on a "governor shaft" which is geared to the main shaft, and which has no other office than that of carrying the governor and the eccentrics. It is evident that so radical a departure from standard design must have been caused by the possibility, actual or presumed, of thus attaining some very important result. A little study shows plainly what this supposed advantage must be.

The necessity of providing for efficient performance at high speeds of rotation has been seen to have compelled the adoption of a positive motion valve-gear; the adoption of this gear led to the use of a powerful form of governor, directly attached to the cut-off eccentric; this, in turn, compels the use of revolving weights, turning in orbits lying in the vertical plane; this last feature, in turn, again made it necessary, apparently, to place the governor on the main shaft, and to meet the effort of centrifugal force by a counterbalancing action, which could then only be obtained by the use of steel springs set in the casings of the governor. But the use of springs is considered by many engineers to be so objectionable, that they would submit to some expense and inconvenience to avoid their application, if possible. The objections are that they are liable to changes of tension and of length while at work, that they never have a definite and calculable strength, that they are liable to break in most unaccountable ways, and at most unreasonable and unexpected times, and that the adjustment of a balance between the two equilibrating forces is often difficult and almost always unsatisfactory. These objections undoubtedly do to a certain

extent exist; but they as certainly are not as serious as is often supposed. The writer has had a long experience



THE CUMMER GOVERNOR SECTION.

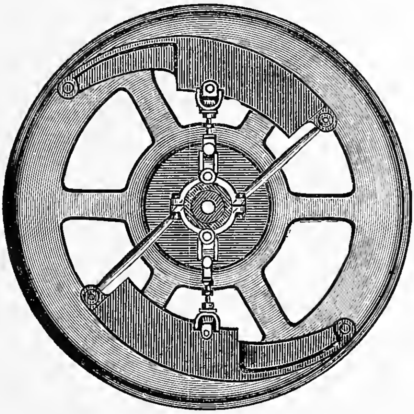
in this direction, both in the use and in the observation of the steel spring for a wide variety of applications, and has never yet seen reason to condemn them unre-

servedly. The principal objection which can be urged against the governor of this class, as usually adopted for the kind of engine now under consideration, is probably the fact that it cannot be reached while the engine is in operation, and that change of speed is thus made impossible except by stopping the machine and making changes in the adjustment of the springs, then trying the speed again, and again stopping to adjust, until the desired speed is exactly attained, which disadvantage is shared by the older arrangement of governor.

The form of the Cummer governor, which has been designed to evade these objections to the use of springs, and to secure certain special advantages, is shown in the above illustration and in that which follows. As has been seen, when studying the design of the engine as a whole, the governor of the Cummer engine is of the same general type as that of the engine last described; but it is mounted upon a shaft, separate from, and driven by gearing from, the main shaft. The governor shaft also carries the eccentrics, one of which is loose on the shaft and is controlled, as to position, by links from the weights of the governor as usual. The governor is thus enabled to shift the eccentric forward or backward and thus by changing its lead, to determine the movement of the cut-off valve and the ratio of expansion.

There is nothing specially remarkable about this part of the arrangement. The position of the weights is seen to be determined, however, by a system of bell-crank levers which connect the middle point of each weight with a vertical rod and chain under the engine bed, and on this rod is carried a set of weights which may be easily reached when the

engine is running. The bell-cranks within the governor casing, move a rod which passes along the centre line of the governor shaft and emerges at the left. This rod engages a large bell-crank at the end of the shaft, through which the load suspended under the engine is sustained. But one spring, and that a small one, is seen in the whole system. The centrifugal action of the governor weights, when at the inner limit of their range, is met by the weights on the scale pan, and the spring is only required to meet



THE CUMMER GOVERNOR.

the additional action of the governor weights when they fly outward, as the engine increases speed. The more nearly an equilibrium is maintained between the action of the flying weights and the balancing load, at the proper speed of engine and at all possible positions of the governor, the more perfectly "isochronous" does the governor become, and the more exactly will the engine hold its speed, under all variations of steam pressure and of load. With this

governor, the weights on the pan can be increased or diminished at any moment, and to any desired amount, whether the engine is in motion or at rest; the isochronous adjustment can be effected as nearly as desired, and the speed of engine may, at any moment be altered, much or little as may be advisable.

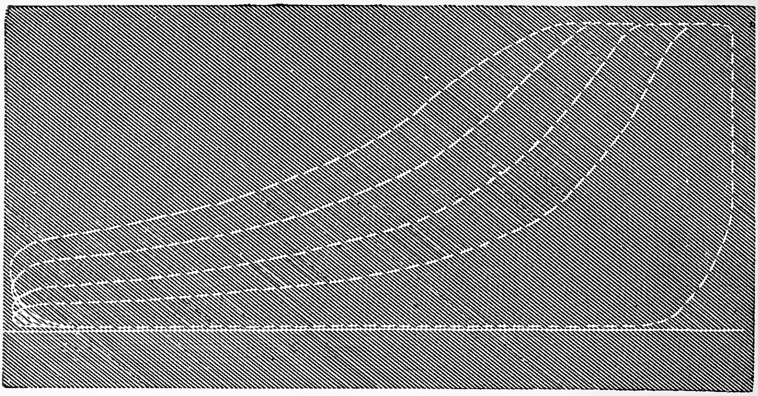
This accessibility of the governor, and the disuse of heavy springs to control it, are the principal advantages of this form of governor. It has also some incidental advantages which are worthy of notice, although of less importance. The governor shaft is comparatively small; this permits the use of very small eccentrics; this reduces friction and load on the valve mechanism, and this, in turn, adds a little to the efficiency of the engine, as a compensation for the introduction of an additional shaft. The one spring used here is smaller than that needed for other governors of the same class, and is relieved from tension entirely at frequent intervals, and the periods of "rest" thus given it are likely to insure an increase in its longevity which may prove to be a point in its favor worth mentioning. It may sometimes, although certainly not frequently, occur that an engine may be required to work, at different times, at certain different, but fixed, speeds. In such a case, it is easy, with this engine, to find a set of weights which when in place, will give each one of these fixed speeds; the engine can then be, at any instant, brought exactly to either speed by hanging on the scale pan the right weight for the speed. The several weights can be kept at hand for use as required. Such an arrangement may be sometimes especially useful in electric lighting.

Several styles of the Cummer engine, other than those which have been described, were built for the market. Those which have been here illustrated are, however, especially fitted for such work as is the subject of this article. Both of the forms which have been described are well adapted to use in electric lighting plants, and are proportioned for high speeds; they are designed for nice regulation and are likely to prove durable, economical, and otherwise satisfactory motors. They are intended for steam pressures of 90 or 100 pounds per square inch, and their rated powers are based upon an assumed piston speed of about 400 times the cube root of stroke, as nearly as it can well be reckoned by the old method of James Watt—a speed more than three times as great as was thought best in the time of that great engineer. Even this speed is not to be considered remarkably great for engines designed and built, as are these, with especial regard to the requirements of high-speed motors. The steam pressures adopted are those generally regarded by engineers as, on the whole, the best for ordinary purposes, and are those beyond which the gain in economy by further increase becomes rapidly less with even the best engines. The point of cut-off is calculated, in estimates of power, to be at from one-fourth to one-fifth stroke, and, as a rule, nearer the first than the last figure. The best ratio of expansion for any given case is to be determined by a comparison of cost of fuel and steam supply with other operating expenses, at the place of operation.

The engine above described has been used, in many cases, to supply power for driving dynamos in electric lighting, and has an excellent record in that field, as well as in cotton

and flouring mills, which demand the most perfect possible regulation.

One of these engines (16x36), at the Cincinnati Exhibition of 1883, was tested by the committee on electric lighting apparatus and found to alter its speed but 2½ per cent., when the whole load, 124 horse-power, was thrown on or off; it varied one revolution per minute with a change of steam pressure of from 90 down to 50 pounds.



The indicator cards, of which copies are given above as taken from this engine, show the method of distribution of steam in engines with positive motion valve-gears, such as are here considered as fitted for direct connection with large dynamos, and for high speed generally. The illustration exhibits a series of indicator diagrams taken from this engine at points of cut-off varying from one-tenth to one-third stroke. It is seen that the steam lines are as straight as those of a drop cut-off engine, very nearly up to the point at which the effect of closing the cut-off valve begins to exhibit itself in the production of the expansion line. The

expansion curve is very nearly that obtained by laying down the hyperbolic curve of Marriotte, and the exhaust is as clean and prompt as need be desired; the back-pressure line closely follows the atmospheric line seen immediately beneath it, and the compression line at the right hand end of the card is quite as good as is often seen in the most perfectly proportioned engine with detachable valve. As the steam follows further and further, the sharpness of the corner between steam and expansion lines gradually becomes less, and the form of that part of the diagram approximates that found in the older forms of plain slide valve engine. For the most generally desired ratios of expansion, however, the form of the curve is satisfactory, and it is evident that the adoption of the positive motion type of valve-gear does not introduce any very serious loss of efficiency in this respect.

THE STRAIGHT LINE ENGINE.

REVIEWING what has been said in this section of engines capable of direct connection to the dynamo, it will be noted that the engines which have now been described have belonged to two classes, differing from each other in two very important respects. In the first, represented by the Porter-Allen engine, we find a form of engine especially, and very ingeniously, designed for high speed of rotation, fitted with four balanced valves, with the object of securing minimum "dead space," and maximum economy and ease of working, and controlled by a governor which differs from the older form introduced by Watt, by several

useful modifications of design, and especially, by being loaded in such a manner that its speed, and, consequently, its power and sensitiveness in working, are greatly increased. In the second class, we find a valve-gear of the Meyer type driven directly by the eccentric, instead, as in the first class, through a link, and regulated by a governor riding on the main or the governor shaft, beside, and directly attached to, the eccentric. The features essential to a "high speed" engine are also embodied in the second, as well as in the first, class of engine.

We now come to the examination of a third-class of high speed engine, which differs as radically from the two preceeding as they from each other. In this new form of engine we find but a simple valve which does duty both as a distributing and as a cut-off valve. A form of engine belonging to this class, with which the writer happens to be familiar, is that known in the market as "The Straight Line Engine."

This engine, so far as it is novel, is the invention of, and also is designed by, Professor John E. Sweet, formerly the superintendent of the workshops in which instruction in machine work was given in the Department of Mechanical Engineering of Cornell University—a position in which he became widely known as one of the most skilful and ingenious mechanical engineers in the United States—later a President of the American Society of Mechanical Engineers. The first of these engines was built at Sibley College, Cornell University, in 1871, under the instruction of the designer. A second, built in 1875, is still in use.

The Straight-line Engine has many interesting and novel

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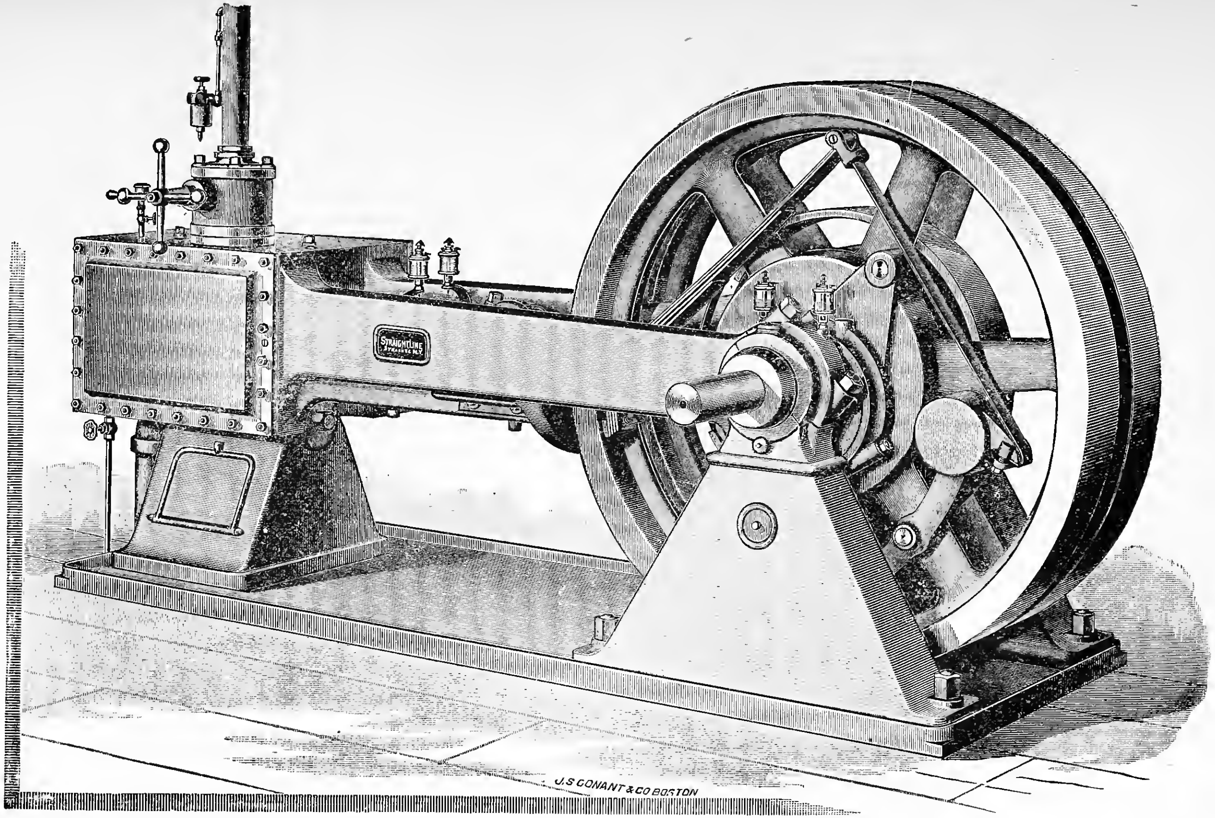


STRAIGHT-LINE ENGINE.

points, which will bear much more extended study than they can be given in the small space which can here be allowed for the description of the engine. The problem, proposed to himself by the inventor, was to design an engine which, while consisting of the smallest possible number of parts, should, nevertheless, be economical in its use of steam, capable of the most perfect regulation attainable with any known device, strong and stiff in every part subjected to the working strains of an engine working at high speed, inexpensive in first cost, and durable as a simple engine can be.

This engine is shown in the accompanying illustration.

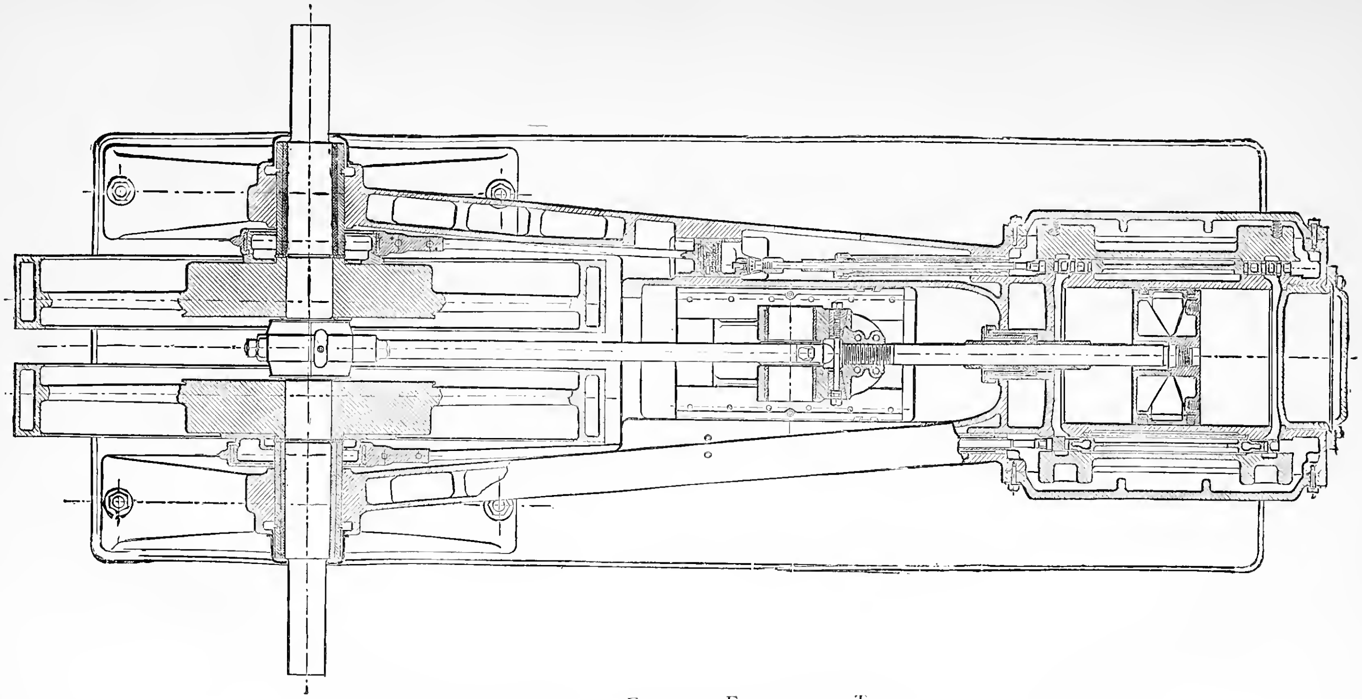
A vertical engine, which is shown at the end of the article, is also designed for all powers; there seems no reason why it should not prove a good style for heavy work; better in some respects, in fact, than the horizontal engine.

The engine takes its trade designation from its peculiar form of frame, which is seen to consist of two perfectly straight diverging struts extending from the end of the cylinder directly to the two main bearings, thus carrying the line of resistance to the pull and push of the connections exactly along its own central line. No possible arrangement could give greater stiffness with the same weight of material. The whole structure is carried upon three points of support, as is the practice with "surface plates," which must, if possible, have an absolutely definite and invariable system of suports, to avoid the slightest danger of "spring." These points are under the main bearings, and beneath the steam cylinder. The two journals receive equal loads; the crank-pin is not subject to the deflecting forces met with where a crank is overhung; danger of unequal wear of journals,

and of springing the pin, is thus avoided very completely. The fly-wheel is placed in twin-form between the main bearings, and also serves as crank, thus making the best of cranks as well as balance wheel. This position of the balance wheel is one of peculiar advantage. By its action at this point, it intercepts heavy and objectionable stresses, which, in other engines, are transmitted to the main shaft; and the reciprocal action of counterweights and equilibrating parts is thus only felt within a mass of metal, which can resist them with perfect safety, and without their being felt in the more sensitive parts of the machine. This arrangement renders the main journal less subject to springing under the loads transmitted through it. To secure better distribution of wear, the crank shaft is allowed some end-play. This end-play, together with the carefully arranged system of lubrication, are the best possible insurance against excessive friction and wear.

The steam cylinder has the appearance of the cylinder familiar to every one, as seen on ordinary plain slide-valve engines. Its valve chests enclose separate double valves for steam and exhaust, and the ports and passages are carried as in those engines. The valve stems have no stuffing boxes, but pass into the chest through unusually long and carefully fitted holes, in a hub, made about five one-thousandths of an inch larger than the rod inside the Babbitt metal bushing, for a length of six diameters or more. The hub is loose in the hole in the end of the valve chest, and is packed at the ends by a washer fitted on a flat seat on the inside. The piston-rod is similarly fitted.

The crosshead is a very long casting which overruns the



Straight-line Engine.—Four-valve Type.

guide at each end at every stroke, and thus is rendered safe against wearing to a shoulder. A pin subject to reciprocating efforts in any part of an engine, whether it rotates, or carries a rotating or a vibrating piece, is apt, in time, to show wear on the two sides in line with the principal pull or thrust, and to lose its cylindrical form. In this engine, such wear is avoided at the crosshead pin, by cutting away the surfaces, which do little or no work, and thus securing overrunning surfaces, which are not subject to this distorted wear to so great an extent. Many other minor points invite attention, but they cannot be here considered.

The principal feature of this design, in connection with that phase of its work which is of especial interest here, is its valve-motion. The valve is a rectangular block, sliding between the seat and a coverplate; is shown in the engraving. Ports are cut through the coverplate, through the valve, and through the seat into the steam and exhaust passages in the cylinder casting, in the proper positions. These ports are double at the ends of the valve, and a single port of ample area is made through the middle of the valve.

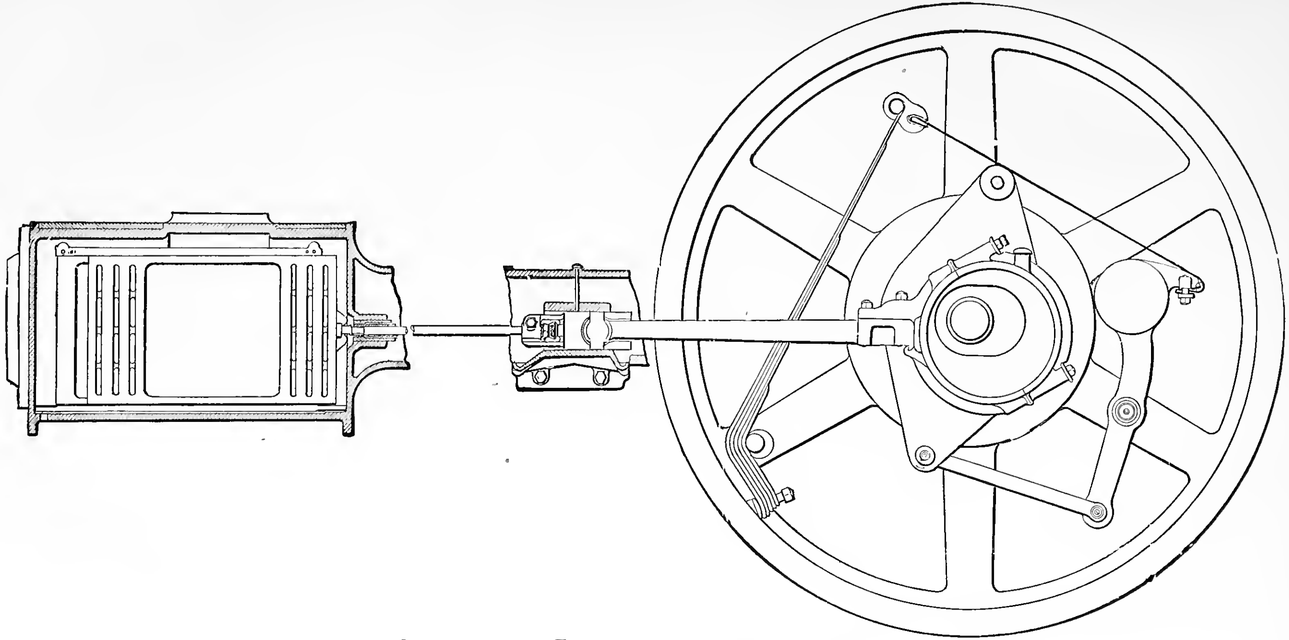
This valve is what may be called a "piston valve" of rectangular section, the space in which it slides having, therefore, also a rectangular section, and permitting the use of a detached coverplate, which, while sustaining the pressure of steam that would otherwise come upon the valve, and thus making it a balanced valve, nevertheless allows any unusual pressure, occurring when the piston comes back to the compression period of its cycle, to raise it, and thus to permit the water which may have caused the pressure to flow back, and thus relieve the cylinder, and obviate all

danger of forcing out the heads. The principal feature of this device is not new ; the writer handled such a balanced valve on marine engines, rated at above 5,000 horse-power, nearly twenty years ago, and found them, so far as his own experience went, perfectly satisfactory. This new application of the principle, however, embodies some new and interesting points. The valve cover is sustained on loose packing strips, which are free to close up upon the edges of the valve, and to take up wear as it occurs. The form of the plate, its domed top, is such as to give it great stiffness against the superincumbent pressure, and thus to prevent pressure on the valve itself in consequence of spring in the plate, and the ports are so placed as to prevent the cutting away of the faces and seats by the rushing currents of steam.

The valve and cylinder ports are not dressed out ; the casting is made so accurately that these edges can be left as they come out of the sand without loss of efficiency in the working of the valve.

The valve is driven by an eccentric, the motion of which is controlled by the governor, and the connection of which with the valve is effected by the peculiar system of linking, seen in the preceding illustration. The eccentric is so suspended from the disc, to which it is attached, that it may be thrown across the shaft by the action of the governor, in such a manner as to give the effect of the once common and well known "Dodd motion." It is carried on a lever, which is pivoted at one side of the shaft, while the governor rod is attached at the opposite side. The singular positions of the eccentric rod and the rockshaft arm enable the alteration of the throw of the eccentric produced by

[*To face page* 106.]



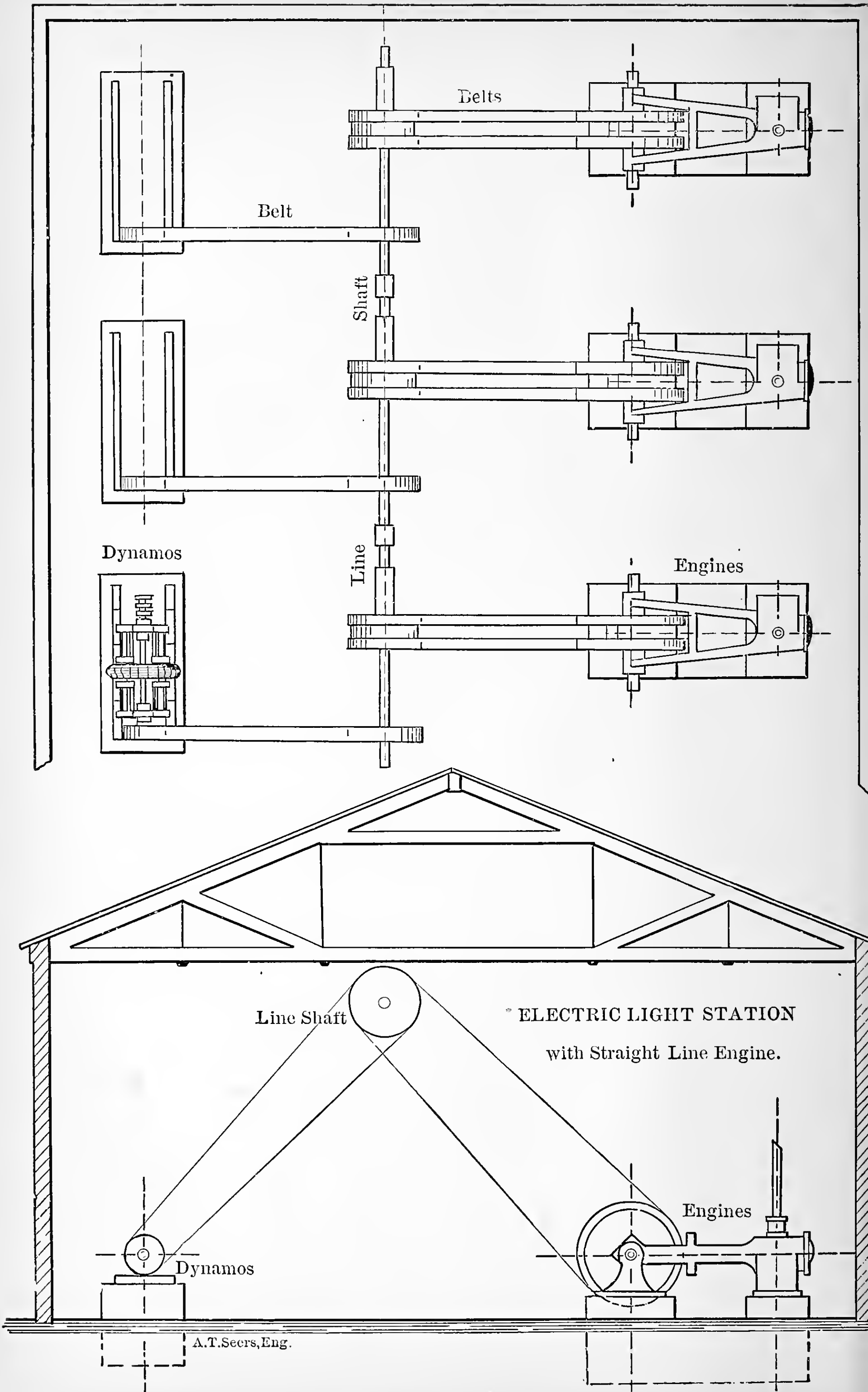
STRAIGHT-LINE ENGINE.—GOVERNOR AND VALVE.

the governor, to be effected without alteration of the lead of the valve, so that the steam may be admitted, at all times, at the same point in the revolution of the engine. This it does, since the line of the eccentric rod is, at the commencement of stroke, in line with the lever on which the eccentric is carried.

The governor is similar, in principle, to those which have been described as used on the last type of engine. It consists of a single weight, or ball, carried on the end of a lever which is pivoted, near its middle point, on one of the arms of the governor pulley, and connected to the spring, by which it is held under control, by a strap extending across to the other side of the shaft to the end of the spring, which is there secured to the rim of the pulley. The action of the governor is substantially the same as that of those which have been already described. When the speed decreases, the tension of the spring, at the end of the weight lever, overcomes the centrifugal effort of the ball, and the latter is forced in toward the shaft, carrying with it the end of the eccentric lever, and thus giving the valve greater throw, and extending the period through which the steam follows the piston, producing more power and bringing the engine up to speed. The reverse change of speed of engine produces the opposite action of eccentric and of valve motion, and the cut-off is shortened, and the power of the engine is reduced to that needed to give the correct speed. As this governor may be made as nearly isochronal as may be desired, the approximation to correct speed may be made as close as is consistent with the sensitiveness considered permissible. The use of a single eccentric and of a single gov-

ernor ball, and the general simplicity of this combination, are especially pleasing to the engineer. They, however, include the use of a simple valve, and thus restrict the designer, somewhat, in his adjustment of the steam distribution, a restriction which the more complicated forms of valve-gear are constructed to avoid, as it is well understood that the economy of the machine, in its use of steam, is to a certain extent, dependent upon the method of distribution of the steam entering, and of the exhaust leaving the cylinder. The main objection is the fact that the mean pressure of the steam entering the cylinder up to the point of cut-off is necessarily less with a single valve than with the gear introduced by Sickles and Corliss, and their successors, and which have been long standard, and which are admittedly superior in this respect.. Whether the more costly, but more efficient gear shall be used, is to be determined partly by the cost of fuel, and must be settled by the judgment of an experienced engineer in each individual case.

The difference in this respect is not, however, as great as has been by some engineers supposed, and the economical value of heavy compression is now becoming so well understood, that the general impression in regard to this system of valve motion is becoming considerably and rapidly modified. What is lost by the drop of pressure between the boiler and the piston, is partly compensated by the variable and automatically adjusted compression obtained with this kind of motion, as is well illustrated in the action of the Stephenson link as used on the locomotive. With this arrangement, there is also some loss at the exhaust period, but not usually enough to be considered serious. As this



ELECTRIC LIGHT STATION
with Straight Line Engine.

particular engine is operated, this latter loss, and possibly, to a slight extent, the former, are somewhat reduced by setting the valve without lead, or even with "negative lead," *i. e.* so that the engine does not take steam until the crank has just passed the center, and the piston is starting on the forward stroke.

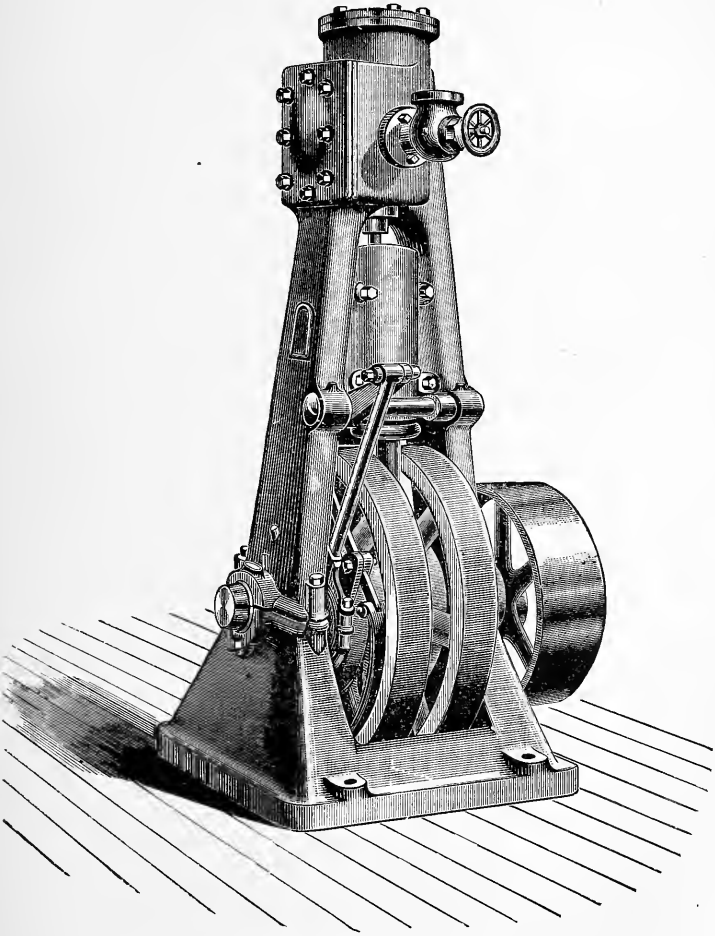
The engine, as a whole, with all its important parts in section, is shown in the above engraving. The unusual quantity of material as compared with earlier practice in older forms of engine, the excellent distribution of that material, the small number of parts, the heavy crosshead, the arrangement of fly wheels, and the form of valve are all plainly seen, as well as the general arrangement and system of connection. The rods and pins, and all running parts, are made of steel; journals are ground to perfect form and polished, and the engine, when completed, is set up in the shop and carefully tried before sending it out, as is becoming the custom with good builders everywhere. The designer has made a special effort to reduce friction to a minimum, and has given the engine easy running piston and crosshead, perfectly formed journals, and a valve gear and governor, which are as nearly frictionless as those parts can well be made. The growth of the engine into its present shape, from the first crude sketches made in 1869, to the finished engine and completed type of to-day, and especially the gradual evolvement of the governor and valve gear from the older forms, would be an interesting subject of study, but it cannot here be undertaken. The survival of the fittest, among these devices, has led to the production of the engine above described.

The Straight Line Engine has been frequently applied

to the driving of electric lighting apparatus. In Penney's arrangement of a station of 120 lights, the connection of power to dynamo is effected through friction clutches, which may, at any instant, be thrown out or thrown in; any two of the engines have ample power to drive all three of the dynamos used, and a reserve is thus supplied to be used in case of the necessity of throwing off one engine for repairs. The current from any one generator is capable of being switched into any circuit, and all parts are accessible for examination and repair. A novel device is that of placing the driving pulleys, on the main line, on separate hollow shafts, independently supported, to prevent the springing of the line shaft by the pull of the main belts. The line shaft runs directly through the jack shaft, carrying the driving pulley on the line.

As this engine is adjusted, with large compression when at regular speed doing the rated work, with negative lead on the valve at that point, becoming positive lead at ¾ cut-off, it illustrates well the efficiency of the class. A 50 horse-power engine, driving a 40 light dynamo, according to the report of the manager at the station, ran at 219 revolutions, and at 220 when 27 lights were thrown off. The writer, testing one of these engines rated at thirty-five horse-power, using a Prony brake to take up the power, counted 233 revolutions, light, and 232, loaded with above forty horse-power; with lower steam, the figures became 231 and 230. A well-balanced valve and a nearly frictionless governor are the elements giving success here. Every good engine, driving dynamos, is

expected to rival this, doubtless, but, doubtless many do not. The simple-valve engine can evidently, as is here seen, be made, by a skilful engineer, to do excellent work.



VERTICAL STRAIGHT LINE ENGINE.

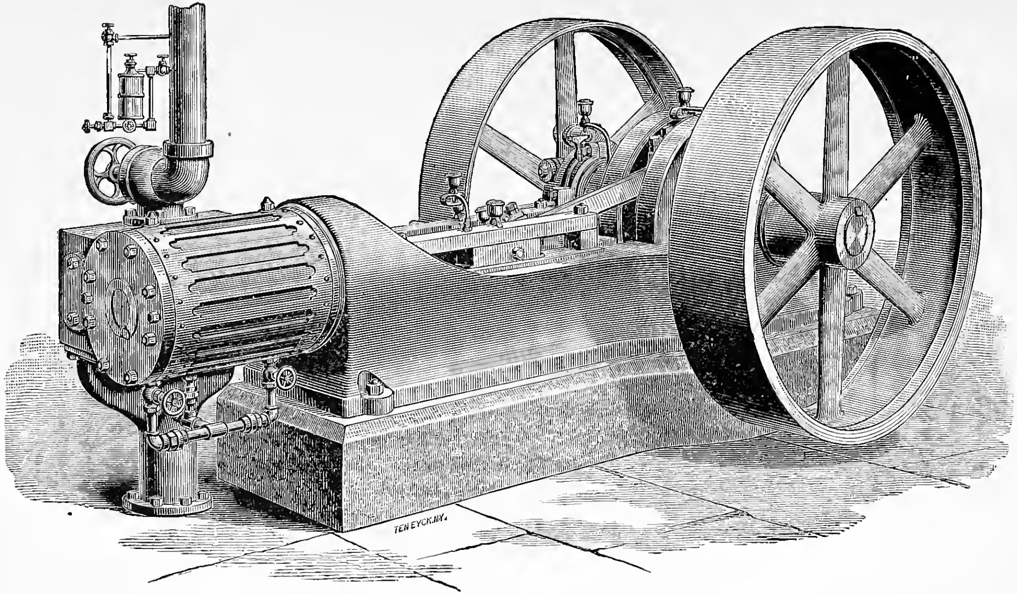
IV.

Engines Capable of Direct Connection.—(*Continued.*)

THE ARMINGTON AND SIMS ENGINE.

THE engine last described, and that to be here examined, are the result of an attempt on the part of their designers to secure a form of engine which should not only be so proportioned and so arranged in the disposition of their details that they may be driven up to the speeds of rotation, now so frequently found desirable, without excessive jar, serious wear, or dangerous heating of journals, but which should also be so simple in plan, so inexpensive in construction, and so easy of repair, that the cost of maintenance, that great tax upon the proprietor of the average steam engine, should be reduced to the lowest possible figure.

In these engines, the possibilities in the direction of increasing speeds, are sought to be made the most of. Their market is not only to be found in the domain of the electrical generation of light, and electrical transmission of power, but in older fields of work as well. The loss of power in the "jack-shafts," or "first motion shafts," of mills and workshops driven by the low-speed engines is an item of no inconsiderable amount in many cases. The tendency is now observable toward the adoption of the high-speed engine, even where not quite as economical in the use of steam, in direct connection with the main line of shafting, through the intermediary of a single belt or pair of gears, or even by directly attaching the crank-shaft of the engine



THE ARMINGTON & SIMS ENGINE.

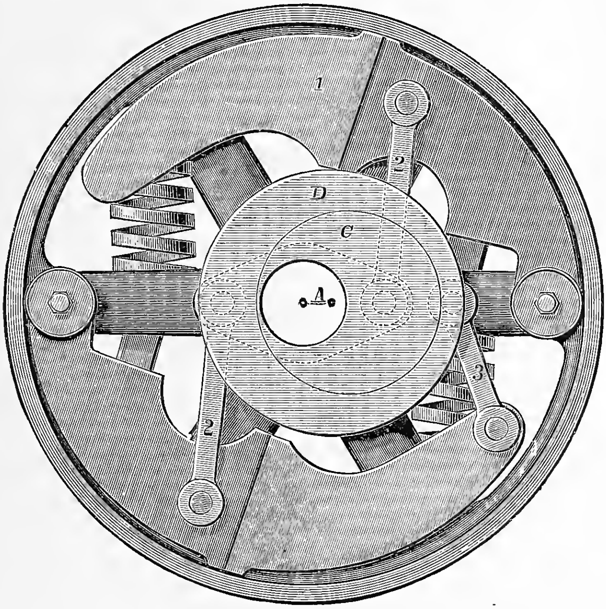
to the main line by a coupling. Many flouring mills and several rolling mills to the personal knowledge of the author, have been operated in this way for some years, and the system will probably become rapidly more general. In this country, the use of gearing for such connections has long been almost entirely superseded by the introduction of belting. The smaller first cost, the diminished noise, the lessened danger which accompanies their failure, and other obvious advantages, have been found to far more than counterbalance the cost of maintenance of the belt. By thus connecting directly to the main line, also, the cost of belting is greatly reduced. As the speed of shafting is rarely less than 150, and seldom more than 250, revolutions per minute, it is not difficult or objectionable to establish this method of connection. The same advantages are then derived that are experienced in the direct connection of the engine to the dynamo-electric machine. The total first cost of power is thus often reduced thirty and sometimes 50 per cent. As has been already intimated, there seems to be no nearly reached natural limit to the increase of engine speeds, except the practical limit of perfection of workmanship and excellence of materials, which limit is being constantly pushed farther and farther back, as the demands upon our engineers and mechanics are more and more exacting. President Westmacott, of the British Institution of Mechanical Engineers, has remarked that, at the high speeds (400 to 500 revolutions per minute) attained by the screws of Thorneycroft's torpedo boats, the engines seemed to run more smoothly than at lower speeds. This has been noted by every builder, and every driver of fast

engines. The author, in handling naval screw engines of short stroke and high speed, has frequently observed this fact, and, after a somewhat wide range of experience with engines of long and of short stroke, of from 15 to 500 revolutions, and of powers ranging from the toy engine built during his hours of leisure when a boy in a short jacket, to marine engines rated at above 5,000 horse-power, at sea and on shore, in the mill and the workshop or on the locomotive, he has never yet seen evidence pointing to any as yet nearly reached limit to engine speed, except that which is imposed by such conditions as we are gradually and steadily modifying, as our knowledge and skill become more nearly able to cope with the difficulties which arise in our constantly changing practice.

It will have been observed that, in all the engines which have been here described as adapted to direct connection to the dynamo and to the "first motion" shaft, some form of balanced valve has been used. It has been seen that one of the conditions of good regulation by a governor, which determines the "point of cut-off," is that the work thrown upon the governor shall be the least possible. This condition evidently points to the use of some expedient, in cases in which a positive-motion gear is used, by which the resistance to motion of the valve, while a change is being effected by the governor, shall be made a minimum; this evidently indicates the advisability of adopting some form of balancing device.

The engine to be here described has been designed with this end in view, as well as with the idea of securing a form of machine which should be simple and inexpensive to

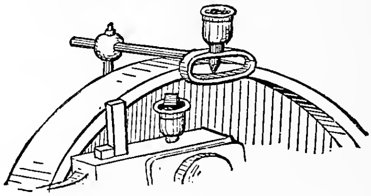
build, and to keep in repair; prompt and exact in regulation under sudden variations of load, and as nearly isochronous in its governor-motion, as is practicable. It is of the same general class with the last several described forms



GOVERNOR AND ECCENTRICS.—MINIMUM THROW.

of engines, but differs from them in its details and in its proportions, somewhat, and, especially, in the form of its valve, and in the devices intermediate between governor and valve. In this engine, the "piston" valve is used, combined with a double port, such as was first used by Allen in the locomotive slide valve. These details are illustrated further on. The engine, as a whole, will be first described.

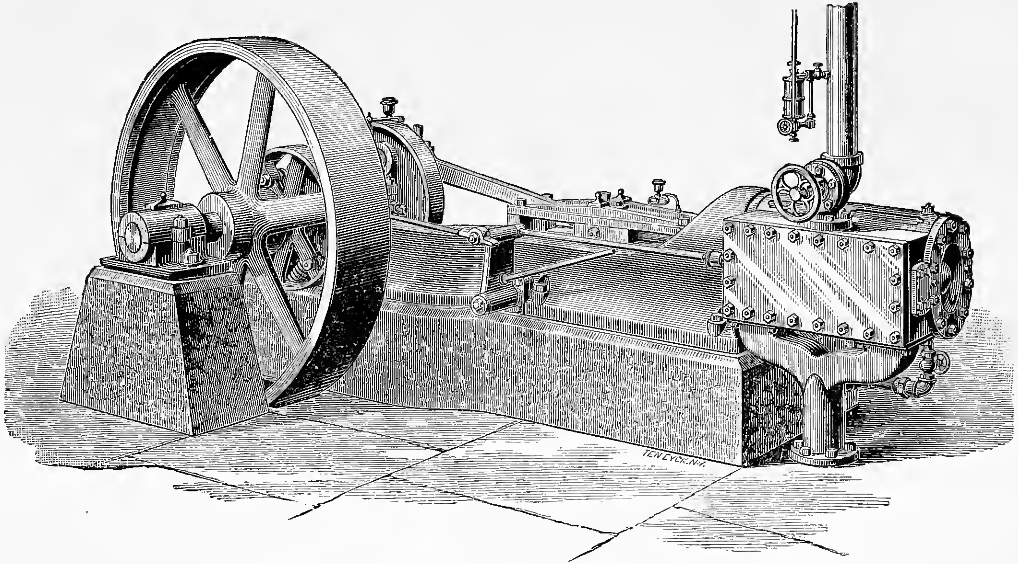
The accompanying engraving present two perspective views of the Armington & Sims Engine, of the styles commonly used in driving electric light machinery. The bed is seen to be of the kind already described in the account of the Porter-Allen engine, heavy, solid, stiff, yet neat, and even graceful, taking the bending stresses of the guides at its upper surface, and insured against twisting strains by the box form of its section. Two main pillow blocks, in the first engine illustrated, carry its steel crank-shaft, and support the two wheels, one of which is a balance wheel, and



CRANK-PIN AND "WIPER."

the other of which is the pulley, from which the engine is belted to its work. The steam cylinder is overhung, and the exhaust pipe is carried down below the floor, clear of the foundation, which latter has a minimum extent, and cost, while amply heavy, and is long and strong enough to carry the engine steadily. In some cases, the frame is made with but one pillow block, and the crank is overhung; the plan here illustrated is, however, a better one when the engine is to be driven up to the now usual speeds of such machines.

The journals are all large, and carefully calculated for the speeds and pressures adopted. The designers make use

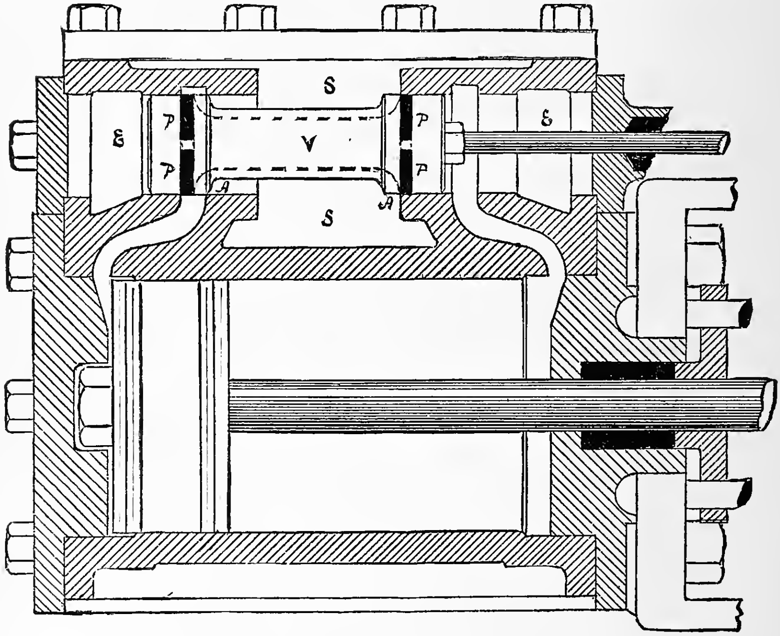


THE ARMINGTON & SIMS ENGINE.

of a method of calculation introduced some years ago, by the author, which is based on the working of marine and stationary engines, under his own management, or under his own observation. The drain-pipes for the cylinder are fitted as usual, but should be rather larger and more carefully planned, than is necessary where the engine has a valve, which may lift from its seat should the boiler at any time "prime" or "foam," and send water over into the cylinder with the steam. The provision for lubrication is a matter of vital importance in all engines of this class. In this engine the "sight feed" is used, in which each drop of oil falls through a clear space, on its way to the point to be oiled, in full view of the man in charge, and any failure of the oil to "feed" is thus promptly detected. The crank-pin is supplied by a "wiper" (see Fig.), which takes its supply of the lubricant from the oil-cup at every revolution of the crank. This device has been used, in very similar form, by the author, on fast marine engines, with perfect satisfaction, and it is found to work well here.

The two large engravings show opposite sides of the engine, and the second exhibits the arrangement of a single wheel, and of the steam-chest and valve mechanism. As is here seen, a governor, of the same type as that exhibited in the articles describing the "Buckeye" and the "Straight Line" engines, is secured to the arms of the pulley on the nearer side of the frame, and is arranged to adjust the position of the eccentrics, which give motion to the valve through a rod and valve stem, the connection between which two parts is made at a point at which they can be conveniently supported by a rockshaft and arm carried at

the middle of the length of the frame. The cranks are, as seen in both illustrations. two discs in which the balancing mass can be secured at any desired point. The width of the pulley carrying the main belt is sufficient to take a belt of such breadth, that the stress shall be about 35 pounds per inch of its width. The main bearings are made with boxes set at an inclination to the horizontal, and provision



SECTION OF CYLINDER.

is made for taking up wear. The crank-pin is of steel, ground carefully to size, as is the universal practice among good builders of this class of engines. In this machine the main journals are also ground. The distance between main

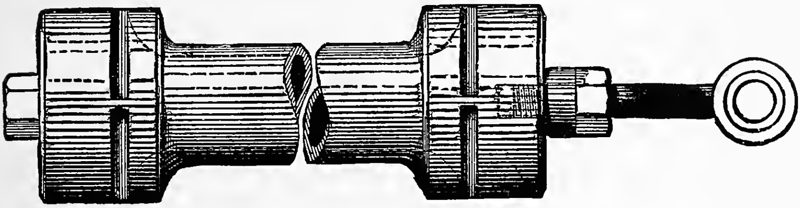
bearings is made as small as possible, to permit high speed with little risk of springing the shaft. The front cylinder head can be removed, when necessary, as shown in the next illustration, independent of bed and cylinder alike.

As here shown in section, it is seen that the cylinder, steam-chest and valve-seat are all in one casting, which is, however, not a remarkably intricate one. It is best shown by the perspective view, while the section next given will afford a better idea of the arrangement of the valve.

The steam-chest, S, S, is in direct communication with the boiler, and the valve, which is of the piston form with a double steam-port (the second port being seen at P, P), is surrounded by the "live steam," thus taking steam at the middle and exhausting it at the ends of the chest, at E, E. The valve moves precisely as does the ordinary locomotive slide valve, and, as here shown, is just taking steam at the piston end of the cylinder, both directly past the shoulder of the valve and through the secondary port at the opposite end of the valve. Thus the steam is introduced, at the beginning of the stroke, through a double length of port, and hence, with unusual promptness when the engine is running at high speed. The consequence is that it gives approximately boiler pressure in the cylinder, and throughout the stroke up to the point of cut-off, if the steam pipe is short and direct, the steam line on the indicator diagram is very nearly perfectly horizontal and straight from end to end. This is a very unusual feature in diagrams from engines having positive-motion valve-gear. The form of this valve is well shown in the accompanying engraving, which exhibits the valve apart from its casing.

All engines of this class will have been seen to be remarkable for the shortness of their stroke of piston, as compared with the diameter of cylinder. The section of the cylinder just given, shows how advantageous is this proportion in enabling the port-space to be reduced to a comparatively small volume. In the engine of long stroke, the port-space becomes seriously large and the compression required to fill it introduces a considerable loss both of power and efficiency, if the valve-gear used is of the type here seen. In fact, it would be probably quite impracticable to secure such a steam distribution as would satisfy the majority of engineers, were the engine of long stroke and a single valve adopted moved by a link, or by such an equivalent for the link as is here used. The total "dead space" in these engines, including piston-clearance, is sometimes as low as 5 per cent. on large sizes. In all cases compression fills this space at every stroke. The piston-valve has been often used by earlier builders, but that here shown possesses a novelty in the double port. Its advantages are the ease and cheapness with which it can be made and fitted, and with which it can be replaced when worn, its perfect balance and ease of working under any practicable steam pressure, its permanence, tightness and remarkable durability when properly cared for and used with boilers supplied with good water. Its disadvantages are, the rapidity with which it sometimes wears, when it is not kept well lubricated, or when it is exposed to the action of steam carrying over from the boiler acidulated or dirty water, the danger of injury to the cylinder or its heads when priming occurs, and the proneness of the attendant to neglect its

repair when it requires such care These disadvantages have sometimes proved to be so serious, as to give many engineers a very strong prejudice against the valve; on the other hand, this unfavorable prejudice seems to be now giving place to a decidedly favorable opinion, assuming that the valve is well made and is to go into good hands, and to be used under proper conditions, and these and some other very successful makers have definitely adopted the piston valve as a feature of their standard designs; it is even coming into use in marine engines of the largest size. In



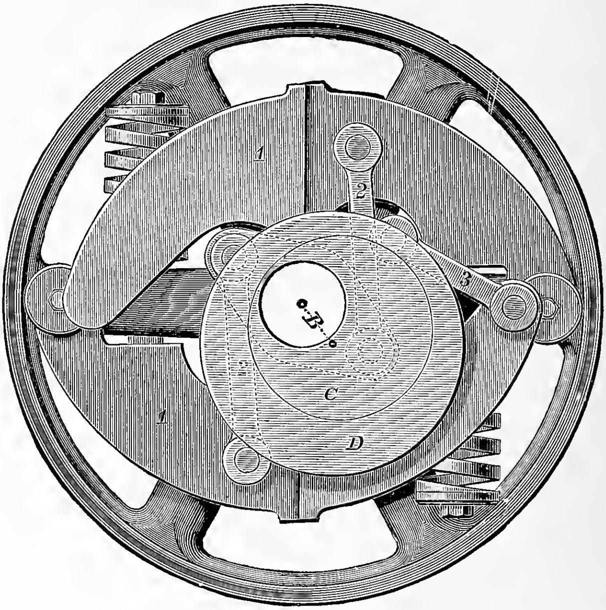
ARMINGTON & SIMS VALVE.

the engine here under consideration, the valve is said by the constructors to have proved eminently successful and to have proven more durable than their earlier constructions, in which they adopted a balance flat valve. It is probably too early, as yet, to fully decide what are the exact relative merits of the two kinds of valve. In this particular case, the removal and replacement of the piston valve can be done quickly and inexpensively, and a spare valve being kept on hand, it is probable that its use may prove economical and satisfactory even where the water used for the boiler is not of the best.

One of the most important, novel, and beautifully ingen-

ious details of this engine, is its peculiar arrangement of governor and eccentrics. These parts are exhibited in two engravings.

The regulator is precisely the same, in principle, as those already described as adapted to the adjustment of the eccentric on the main or the governor shaft. It has the two weights, 1, 1, carried on, and forming a part of arms piv-



ARMINGTON & SIMS GOVERNOR AND ECCENTRICS.—MAXIMUM THROW

oted to the governor pulley, and revolving in the vertical plane as usual in that class of governors. The position of these weights, as determined by the speed and the action

of the springs, determines the position of the eccentrics, C, D, and thus the position and motion of the valve, and the point of cut-off, flying out and giving a higher ratio of expansion as the load on the engine is diminished, or as steam pressure rises in the slightest degree, and a lower ratio as these conditions are reversed. In the device here adopted, however, the valve is driven by an eccentric which is "duplex." One eccentric, C, is set inside another, D, and connected to the governor arms in such a way that, as the weights separate with increasing speed of engine, both eccentrics are turned on the shaft so as to cause their "throws" to coincide, or to separate, as may be necessary. When they coincide, the travel of the valve is due to a greater total throw, B, and is a maximum; when they are separated as far as possible, the throw becomes A, and the travel is reduced to a minimum. The action is almost precisely the same as that of a "Stephenson-link," worked between full and mid-gear. When the two eccentrics give maximum travel, the action is that of the link-motion in full gear; when they are at opposite sides of the shaft, the action is that of a link in mid-gear. By setting them at intermediate points, the throw is made that is required to give an intermediate action of the valve, and thus the distribution of steam is made to accord with the demands of the work by such a variation of the ratios of expansion and of compression as is obtained by the link-motion, and, in this case, with the advantage in promptness of opening and of closure obtainable with a double-ported valve. The range of action given in this engine is sufficient to permit a

range of cut-off from o to about three-quarters stroke. The lead remains unchanged, and the compression increases as the ratio of expansion is increased.

The springs of the governor are used in compression. The distribution of steam at the usual speed, and with full load, is shown by the accompanying illustration, which is a copy of an indicator diagram taken from one of the engines driving the large dynamos at the Edison station in New York city. These engines are coupled directly to armatures,

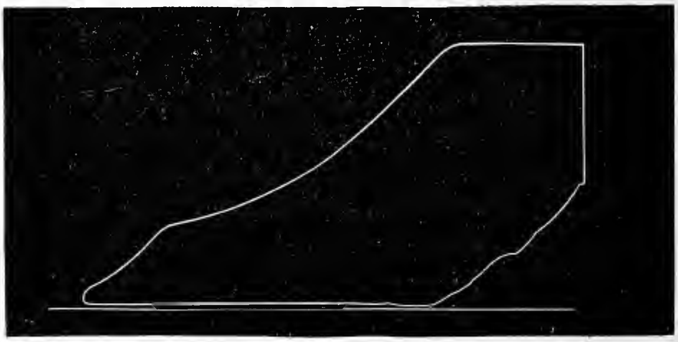


DIAGRAM TAKEN AT THE EDISON STATION.

and make with them 350 revolutions per minute. One of these engines was recently kept at work 17 days, making over 8,400,000 revolutions without stopping, and then was not stopped because of any difficulty with the engine. When examined by the author, they were doing their work steadily and smoothly, and were not appreciably affected by the sudden changes of load produced by throwing on and off any considerable proportion of the lights on the circuit.

This engine illustrates well the perfection of regulation attainable by these positive motion valve-gears attached to this form of governor, to which attention has already been called. At a trial of engines of this make made by the author, to satisfy himself in regard to their action under varying load, 25, 50, and sometimes 60 Thomson-Houston arc lights were thrown on or off, and the variation of speed was but one and two revolutions, respectively, in 280. No special preparation or adjustment was allowed in this case, and there is no reason to doubt that still closer regulation and more perfect isochronism are attainable, if they, at any future time, should prove to be desirable. These engines, 9½ by 12 inch cylinders, had never been before tested, and had done no work until started under the direction of the author. The lamps demanded very exactly 0.7 horse-power each, a fact which indicates that, as connection is there made, there can be but little lost power between the engine and the lamp. The form of card under load is seen below.

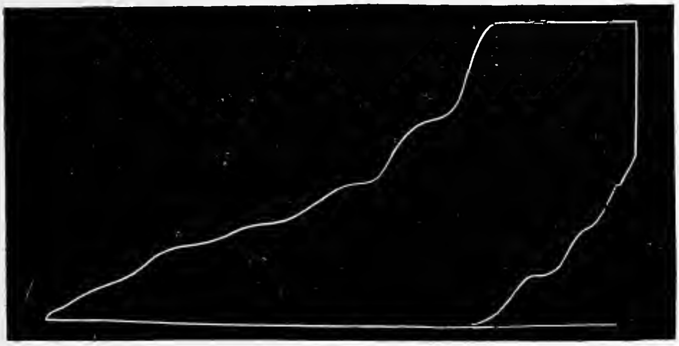


DIAGRAM TAKEN FROM A. & S. ENGINE.

The success here obtained in the use of a single valve is as encouraging as it is remarkable. While it can hardly be expected that the economy of this system, other things being equal, can be fully up to that obtainable with the more elaborate forms of valve-gear previously illustrated, there is no question that it is so great that these simple forms of engines will be able to find a market in that very wide field in which their extreme simplicity of mechanism and their moderate cost, as well as their successful operation at high speeds, are qualities which compensate any such differences in cost of the steam supply. If the same distribution of steam, and the same economy is obtained with the one form of valve motion as with the other, and if, as is the case to a very satisfactory degree with these engines, a correct form of indicator diagram can be obtained, it is to be expected that the engine will be economical in its use of steam. The increasing compression here noted with increasing expansion is a decidedly advantageous feature, as it has an important influence in checking losses by "cylinder condensation" at high ratios of expansion, while also reducing the waste due to large clearance spaces, where such exist.

Every engine and every machine of importance, or remarkable in any respect, as in such a combination, of ingenious devices, effective combination, and efficient operation as is here illustrated, is, invariably, the outcome of a long period of progressive invention, unintermitted experiment and more or less steady growth from an initial stage to its condition of successful adaptation to the demands which it is especially fitted to meet. The Armington &

Sims engine is no exception to the rule, and its inventors and makers, as has been seen, are fortunate in having been able to reap so satisfactory a harvest after so long a period of growth and ripening. The engine is now built, not only in the United States, but in Canada, Great Britain, France and Austria. This American engine is in use on many foreign steamers, and in numbers of European buildings, public and private. It drives the dynamos in the British Houses of Parliament.

V.

Fast Engines of Peculiar Design.

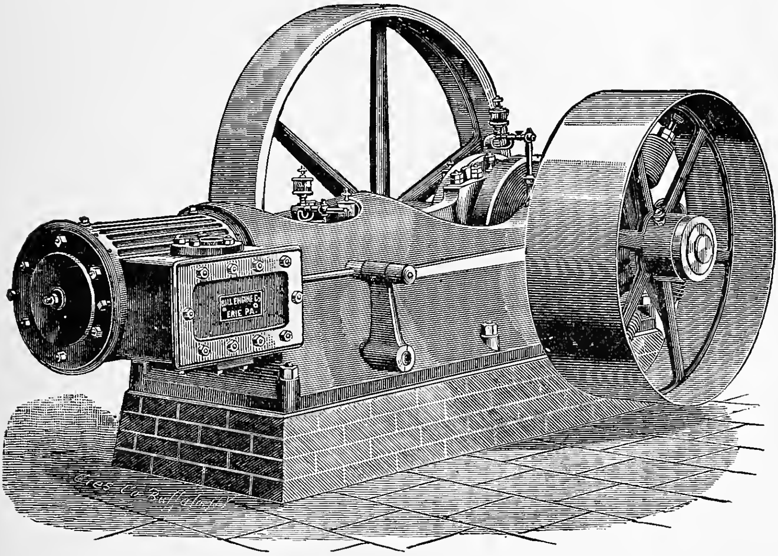
BALL'S DYNAMOMETRIC GOVERNOR.

THE forms of steam engine which have been described in the preceding articles have been chosen as being fairly representative of what may be termed standard types of engine as built by makers of reputation. It will be seen that they present to the student of the steam engine several distinct forms of machine, each of which is now acknowledged to be well adapted to produce a certain result in the application of heat energy, through the medium of steam, to the production of power, and that each is especially fitted to do its work under certain definite conditions, which conditions are less completely met by the others. Each is well-known in the market as an engine which has taken its place among those which have passed the experimental stage and may be relied upon to do good work if well built and put in operation under the conditions that it is designed to meet. They embody ideas and inventions which have grown into form during years of experiment and faithful trial and the variety of makes to be found in the market belonging to each class, and differing only in the design and construction of details, proves that the main principles upon which each class is based are well established and sound.

The engines now to be examined are distinguished by certain peculiarities of design and construction which mark,

in some cases, new departures, in other cases, peculiar ways of reaching the end at which more familiar devices were aimed.

It has been seen that the regulation of the steam engine has been found to be one of the most important matters to which the attention of the engineer has been called. For many purposes, the uniformity of motion of the engine is an even more important quality than its economy in the use



THE BALL ENGINE.

of fuel, or in all running expenses. A slight change of speed in an engine driving dynamo-electric machine will seriously injure the value of the light, in nearly every location, and may sometimes entirely destroy it ; a moderate variation of speed in the motor of a cotton mill making fine goods may break more threads in the spinning department

or do more injury in the weaving room, than would be compensated by the difference in economy between the most efficient "automatic" engine ever made and the most wasteful engine in the market. The principle of regulation of the steam engine has been, from the time of the application of the old "fly-ball" governor to the Watt engines of a century ago to the present day, that of making the speed of the engine determine the amount of steam that shall be supplied to it. In the first engines used in the driving of machinery, in the old "Albion Mills" erected by Watt and his partners in London, in 1786, and for 50 years afterwards, the governor adjusted the supply of steam by moving a throttle valve. The governor was next arranged to determine the point of cut-off by Zachariah Allen, of Providence, R. I., in 1834, and by George H. Corliss, in 1849, to adjust the trip of his detachable valve-gear. From this latter date, it has been the universal custom to so apply it in all engines in which uniformity of motion and economy in the expenditure of steam were the controlling considerations in their design. The method of accomplishment of this result has been seen in the preceding pages, as practiced by Corliss and Greene, and by the constructors of positive-motion gears which have been the later outgrowth of modern changes in the application of steam power.

Now, after half a century since the grand step taken by Zachariah Allen has passed, and a generation after that taken by Corliss, a new principle has been introduced into the construction of the steam engine, viz., the control of the speed of the machine, so far as it is due to the varying load, *by that variation of load*, making the cause of the irre-

gularity of motion its own corrective, and placing the regulating principle between the work and the engine in such a way that the latter may be made to preserve any given speed with perfect uniformity, so far as it depends on the load, or causing the speed either to be increased or diminished to any desired extent by any given variation of load.

This idea, like all valuable inventions, has not been the result of a single thought or the product of a single brain; it has been floating in the minds of thoughtful engineers for a long time. It was proposed to the author, by one of the generation of inventors just passed away, years ago; but, in its present form, it became practicable only after the introduction of the high-speed engine had permitted the use of the form of centrifugal governor seen in the engines last described. The engine about to be considered embodies the first practically useful application of this principle, in a practically successful form of engine.

The Dynamometrically Governed Engine is the invention, so far as it differs essentially from other engines of its class, of Mr. F. H. Ball, of Erie, Pennsylvania. In its general form and in the details of construction, generally, it resembles the last two engines which have been described. It has a single-valve, positive motion valve-gear, and the solid compact structure characteristic of all the so-called high-speed engines. The accompanying illustration will give a correct idea of its form and proportions.

The engine bed is of strong and stiff construction, and very similar to others with which the reader has become familiar. The steam-cylinder is overhung and bolted to a faced flange as in the Porter-Allen engine. The main pil-

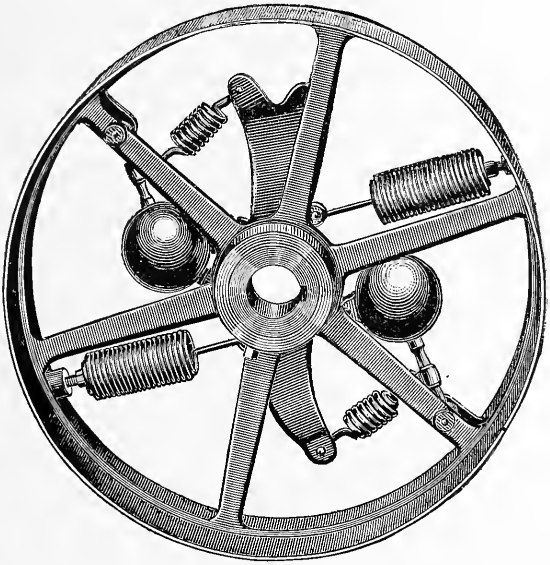
low blocks are set in the bed of which they form a part, and their caps are placed at an angle with the horizontal plane, as is sometimes done in marine engines, and less frequently in stationary engines. The system of boring the seat for the cylinder, aligning the guides for the cross-head, and boring out shaft-bearings, here adopted, gives perfect alignment; and the preservation of the alignment is insured by this unification of parts formerly detached. As is the case with all good engines, the fitting parts are made to standard gauge, and a system of inspection insures good work. Packing is dispensed with, and joints are made tight, by securing exactly plane, and perfectly smooth, surfaces, at abutting points. The wearing surfaces of the valves, and other rubbing parts, are scraped to shape and exactness of form, by the aid of surface plates. The valve is made tight under steam-pressure, the form of the valve being such as to permit this rather unusual operation.

The Ball Engine has a short stroke and high speed of rotation, ranging as now built, from 7 to 10 inches diameter of cylinder, 10 to 12 inches stroke of piston, and making 250 to 350 revolutions per minute. These proportions are adopted, probably, principally with a view to meeting the demands of electric lighting.

The essential and most peculiar feature of the Ball engine, and that which gives it a place in this little treatise, is, as has been already stated, its governor.

The Ball Governor is, in the main, like the governors which have been described as controlling the several engines which have been immediately herein before described. It consists of a "governor-pulley," from the arms of which

are swung a set of weights, which are arranged to move in the plane transverse to the shaft on which the pulley is carried. These weights, or balls, are restrained from moving outwards, under the influence of centrifugal force, by a set of strong steel helical springs, secured, at one end, to the balls, and at the other, to the rim of the pulley. Any movement of the weights, in either direction, causes a motion of the



THE BALL GOVERNOR.

eccentric, resulting in the alteration of the throw of the valve in such a direction, and to such an extent as to bring the engine very exactly to speed. To this extent, the Ball governor is identical, in its general construction and in its principles and mode of action, with those already familiar to the reader. To this extent, it is possessed of the same

qualities as the others of its class, and it has been seen that good workmanship and correct proportions and adjustment may give wonderful nicety of regulation.

To this governor, as commonly built, Mr. Ball adds a remarkably ingenious, and singularly simple yet perfect, invention ; it is exhibited in the accompanying figures. The first of these illustrations shows the governor-pulley detached from its shaft, and does not show the eccentric; it presents only the essentially novel part of the device.

It is seen that, attached to the radius-bar of each ball, is a small spring, connecting a point near the fulcrum of that lever with the extremity of a strong, peculiarly shaped arm, projecting from the hub on the shaft which is seen within the hub of the pulley. The governor-pulley is set loosely on this inner hub, which latter is keyed fast to the shaft. The arrangement is evidently such that, the shaft being turned by the engine, the effort must be transmitted through the small spring to the weight arms, thence to the pulley, and from the latter to the load to be driven, through a belt carried on that pulley. The effect of this curious disposition of parts is easily seen : Suppose the governor to be so adjusted that, at normal speed and under the rated load, the supply of steam and the distribution of that steam, are precisely correct, as intended by the designer of the engine. Now, if a variation of steam-pressure should occur, the governor at once meets the consequent change of speed by a corresponding change of steam-distribution, and the variation of speed is restricted to a range, which, if the governor is well proportioned and well adjusted, may be

quite imperceptible to the senses, and hardly measurable by count.

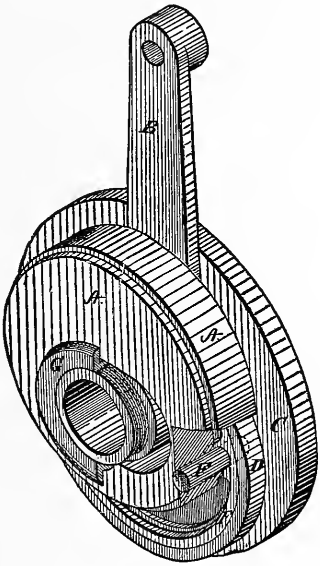
This governor here acts like all the others. But, suppose the steam pressure to be unchanged, and the load to vary—we now have a new movement introduced. The force exerted in driving the load is transmitted through the small springs which are peculiar to this governor, and which connect the main shaft to the driving pulley, through the governor. The instant that any relaxation, or any increased tension, is felt here, the relaxation or the extension of the springs, so produced, causes a change in the position of the weight-arms, and a corresponding alteration in the position of the eccentric; and the steam supply is at once readjusted to meet the variation of load. This may be done so promptly and so exactly, that, however much the load may vary, the speed of the engine remains precisely the same. Load may be thrown on and thrown off to any extent that may be found desirable or necessary, and the engine goes on with its fluctuating task without an instant of visible change. Should both steam-pressure and load vary at the same time, the load.strings set the example of changing the steam distribution to meet the new conditions, and the governor-springs controlling the balls are immediately seen to yield to the effect of the varying steam-pressure, and to continue their motion until the flying weights have set the eccentric in correct adjustment to give the right speed. If the governor is perfectly isochronous, the new adjustment meets the case exactly, and the engine runs at the intended speed as before. The load-springs may even be so adjusted that an increase of load may produce a decrease of

speed to any desired extent, or, even more commonly and usefully, so that *an added load may give increased speed.* This latter is done in some cases when driving electric lights, and also in saw-mills, and for other kinds of variable work. In the former case, the engine is adjusted to give standard speed when driving full load, and to reduce its speed as lights are turned off; in the latter, the engine runs at speed while the saw is cutting, and slows down when the work is off.

The next figure shows the eccentric. *A* is the main eccentric having an elongated shaft opening; to this eccentric is attached the arm *B*, of which the outer end is pivoted, allowing the eccentric to swing across the shaft; this motion controls the time during which steam is admitted, each stroke. This swinging motion is controlled by the rotation of the disc, *C*, in the following manner: The disc has a flange, *D*, on its side, which is eccentric to the shaft, and on the inside of this eccentric flange is a ring, *E*, which engages with a stud, *F*, in the main eccentric. Thus the rotation of this disc forward and backward causes the eccentric to swing across the shaft. The disc has a sleeve encircling the shaft and projecting through the elongated shaft opening in the main eccentric, and on the end of the sleeve is a flange nut, *G*, which holds the parts in place. The rotation of the disc is produced and controlled by the governing forces; the centrifugal force of the weights met by suitable springs; and the resistance of the load equilibriated by the centrifugal force of the weights.

This form of governor is a very safe one, as, should breakage of load-springs occur, the engine slows down or

stops. The risk of injury of this kind is unimportant, however, if the springs are properly made, as the load carried by them is insignificant. A 50 horse-power engine, at 300 revolutions per minute, carries a load of but about 500 pounds on each load-spring. If correctly proportionated and made, they should endure indefinitely. The endurance of all these springs is the greater for the periods of rest frequently given them, and for the fact that they are, much of the time, under very uniform tension.

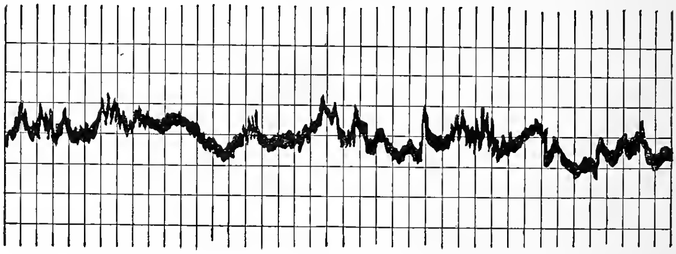


THE BALL ECCENTRIC AND CONNECTIONS.

The practical result of this novel modification of old methods of regulating the engine is that the regulation of the steam-engine now can be made to cover more than the

simple preservation of a fixed velocity of rotation. It is now possible to determine, within certain limits, not only what degree of variation from normal speed shall be permitted, but also what shall be the normal, and if desired, varying, speed of the machine, with varying load. It may not only be made to run at a certain fixed speed, but may be caused either to increase or diminish the speed, according to a fixed, and economically desirable, law. This new principle will probably find many applications, although such problems have rarely come to the consideration of the designing engineer, hitherto.

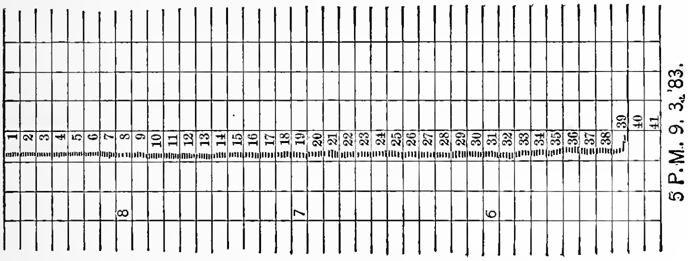
The accompanying peculiar diagrams are taken from the recording apparatus of the "Moscrop Indicator," an instrument which automatically and continuously records the speed of the engine and its variations. Each revolution produces a dot, the height of which above the base-line indicates the speed. The first of the two diagrams is from an



MOSCROP SPEED DIAGRAM.—FAIR REGULATION.

engine of 250 horse-power, fitted with an "automatic cut-off," and furnishing power to a paper mill. It is claimed to do good work; but the author has no personal knowledge of it.

The second is furnished, by the owners of the Ball Engine, as illustrating fairly an equally trying case. The author has other cards of this kind which, with great variation of steam-pressure, nevertheless are very smooth, although not as smooth as that here reproduced. They are also interesting as showing how useful a recording speed-indicator may be. Such records are more satisfactory, in comparing speeds of engines, than are even the best of counters, and vastly more satisfactory than counting by the watch, as they exhibit the rate of each revolution, together with the variation of rate for extended periods of time.



MOSCROP SPEED DIAGRAM.—BALL ENGINE.

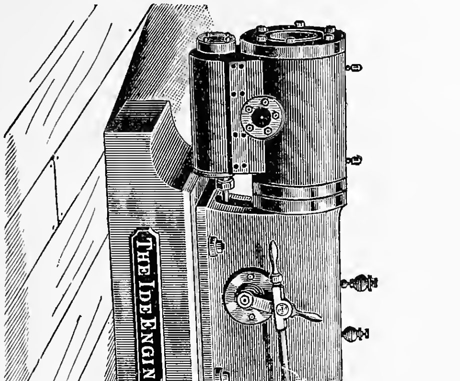
This engine, with its novel governor, is one of the most interesting products of mechanical ingenuity that has been seen since the days of Watt. It will probably have but little influence on the vitally important matter of steam-engine efficiency, as that term is customarily applied, that is to say, upon the economy of the engine in consumption of steam and of fuel ; but it will undoubtedly, in many of its applications, be found to have a very important effect. Mr. Ball has since the introduction of this device also designed other engines of the earlier types.

THE IDE ENGINE.

THE engines which have been described are by no means the only engines which are deserving of mention, and of careful study, as illustrating the peculiarities of the best modern practice in the field which it has been the object of the author to explore. A number of other engines, of one or another of the classes which have been described and illustrated in the preceding articles, have nearly or quite equal claims for consideration. Of these engines, only typical or representative examples have been sought, and have been selected from the machines with which the author is most familiar. One more engine may be here described—not as possessing the singular novelties of design which distinguish some of those already examined, but as affording a good illustration of the principles and practice which have come to be recognized as distinctive of the latest phase of that progress, which has recently been so rapid, in the direction of improved methods of construction, as well as of design, and in the application of the modern materials of construction. The engine is one with which the author cannot claim that personal familiarity which has led, in some cases, to the selection of those which have been previously considered; but a description, such as is to be here given, will show that it may fairly be taken as a representative of the best practice, in matters of detail, which it is the special object of the writer now to exhibit.

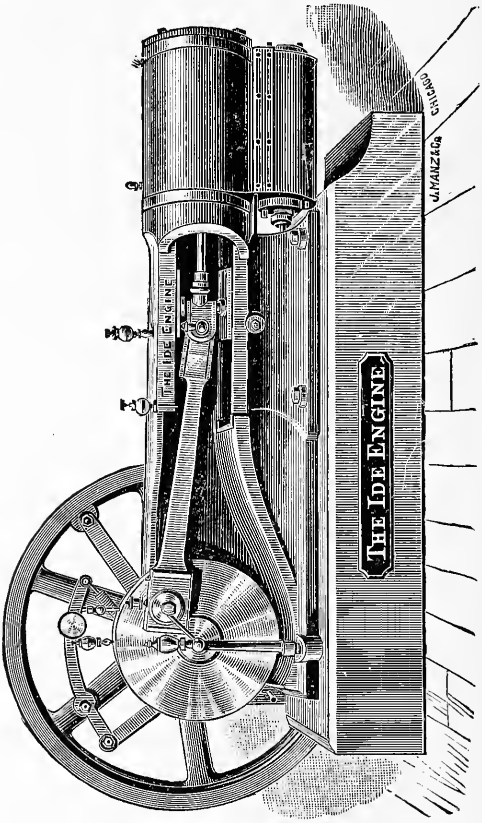
The Ide Engine is of the same class with all the engines described in the preceding section—a high-speed engine, intended to be driven up to high power and to occupy small compass; to regulate with all the accuracy desired in

electric lighting, and in the spinning of fine cotton; to have good wearing qualities, and to be economical in its use of steam and of fuel. The illustrations exhibit its general form, and the more important details of the machine.



Examining it in some detail, it will be observed that the frame, although of novel design, is of the same general form with those which have been already described in this class,

possessing that solidity and rigidity that have been seen to be an essential feature of all successful high-speed engines. The main pillow-blocks are formed in the frame; and the cylinder is secured at the opposite end, overhanging as in



THE IDE ENGINE.

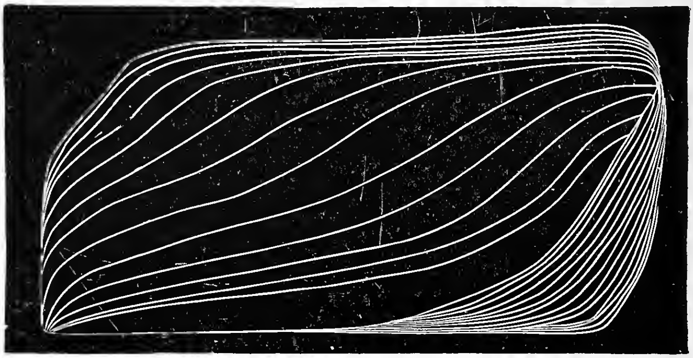
cases already familiar to the reader. The crank-pin is set in a disc, which permits counterbalancing, and gives great strength. The connecting-rod is tapered from the crank-

in to the crosshead-end, in the manner now common to all fast-running engines. The outlines of all visible parts indicate strength and stiffness, and are very neat in design.

The valve-gear and governing mechanism are shown best by the view of the opposite side of the engine, given in the next engraving. The piston-valve is adopted, and is placed directly under the steam-cylinder. This arrangement permits most complete drainage of the cylinder, and thus lessens the danger of accident, should the entrance of water with the steam occur to any serious extent. The placing of the valve at the side is not an unusual feature of this class of engine; but the arrangement here adopted is, in this respect, still more advantageous. This arrangement also affords a means of getting an equalization of the travel of the valve relatively to that of the piston, which is an advantage. Still another advantage is that this position of the valve-chest gives dry steam from the steam-chest, by causing it to act as a trap, as well as drains the cylinder of water that may have condensed within it. The connection with the steam pipe is made above the line of connection between the steam-chest and the cylinder, and it is thus rendered possible to remove the former, and get at the valve without disturbing the steam pipe.

The regulation is effected by a governor of the class adopted in all engines of this kind, and the regulation and the action of the valve are similar in character and in precision to those seen in engines already described. The range of power, and the distribution of steam at various points of cut-off, are shown very beautifully in the indicator diagram here given, which was obtained by suddenly throwing off

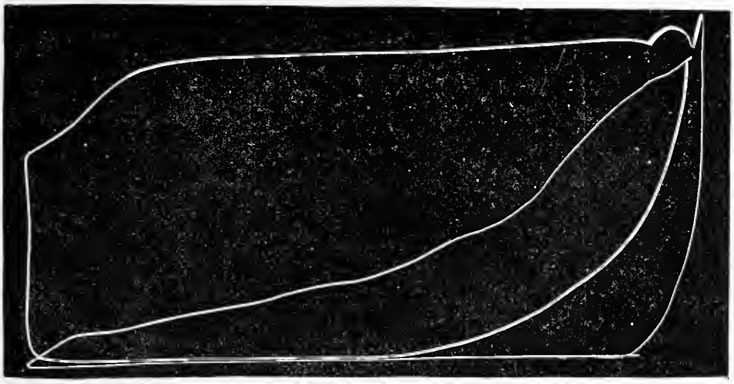
the load; each revolution gives a distinct "card." Steam may follow from the beginning nearly to the end of stroke, with good exhaust and an excellent range of compression. The speed of engine was here 225. The card was taken by loading the engine to its maximum power by a Prony brake, and then taking the diagrams while the governor was adjusting the steam supply, the brake being at the moment released. The smallest card is therefore a "friction card." The smoothness of action of the regulating mechanism is shown by the uniformity with which the power falls off and the cards diminish in area.



SERIES OF INDICATOR DIAGRAMS.—IDE ENGINE.

The next diagram shows the range of work which such engines are capable of doing, and illustrates very finely the change in the distribution of steam which takes place in this accommodation of the power of the engine to its load. It is seen that the compression, as well as the expansion, gradually changes in amount as the power varies, both acting to reduce the area of the diagram with diminishing

power, or to increase it as the required power becomes greater. A very interesting effect of this change is to give increased economy in the use of steam by checking cylinder condensation, the greatest known source of waste of heat, just when that loss becomes most serious in both absolute



INDICATOR DIAGRAM.—IDE ENGINE.

and relative amount. In some cases, the economy obtained, with considerable expansion, by the introduction of large compression, has amounted to above 10 per cent. Where superheating is adopted, this gain is less; but in the usual case, using saturated steam, the use of the valve-motion, of which an example is here illustrated, brings with it a very important advantage; and nearly all builders of such engines are now agreed in testifying to its value. The lines of indicator diagrams obtained by the author from this engine are unexcelled. The recent types of this engine will be described in a later chapter.

One very important feature of recent progress in the construction of the steam-engine is well illustrated in the Ide

Engine, and affords a special reason for studying it; this is the extensive use of steel in its running parts. Within a few years it has become possible to obtain from the makers of Bessemer and "Open Hearth," as well as of crucible, steel, a quality of metal which earlier could not have been obtained at all. This is a steel which is distinguished, chemically, by its low percentage of carbon and its relatively high proportion of manganese, and physically, by its wonderful combination of ductility and strength. As the proportion of carbon decreases in steel it loses strength; but it gains ductility and malleability in a far higher ratio, and thus it happens that the softer qualities are much better fitted for use in machinery than are the very best of wrought irons produced by the ordinary process of puddling. The former are strong, tough, amply hard for all such uses, and perfectly homogeneous; the latter are less tenacious, often not as ductile, and are never homogeneous; but are full of "cinder streaks," and have a fibrous structure that is objectionable, and is never seen in steels. These steels are all made by casting molten metal into ingot moulds, and thus securing comparative freedom from cinder and defective structure.

The soft steels are displacing iron in every direction; and the probabilities seem to be that in the course of time, in the coming "Age of Steel," iron, puddled as is now usual, will be entirely displaced by these, properly so-called, "Ingot Irons." The Ide Engine, as well as other engines now coming into market from the shops of the best builders, illustrate this change of material. It has its piston-rod, its connecting-rod, its valve-stems and links, and its smaller

journals, all of steel. Large castings are not usually made in steel in this country, but all small parts are coming to be made in that remarkable metal.

ENGINES OF THE NEW YORK SAFETY STEAM-POWER CO.

In the course of the somewhat extended series of descriptions of standard forms of engine which is now soon to be closed, it will have been observed that the tendency has been toward the reduction in number of parts, and increasing simplicity of mechanism as the speed of engine is increased. The earlier types of engine having detachable cut-off apparatus as a part of the valve-motion were engines of moderate speed of piston and of comparatively long stroke, and, therefore, of even more moderate speed of rotation. The latter forms of standard engine are of simpler construction, and of higher speed of piston, and of much higher speed of rotation. This difference is not only due to the necessity of reducing the number of parts and securing greater positiveness of action in the valve-gear, but it is also due to the more general recognition of the fact that economy of steam and fuel consumption is but one of the economies to be studied in the use of steam as a motive power, and that the cost of securing great economy of steam and fuel may be such as to more than compensate the saving effected by such expenditure. This is especially true of small powers, and common experience has shown that it is seldom advisable to construct complicated valve-gears for such engines, as the cost rarely comes within the commercially economical limit. This principle has probably been carried too far; and the author has no doubt that engines of

the higher grade may be often found commercially economical for even very small powers. The field for the simpler class of small engine, nevertheless, is enormously extensive; and the number annually built is very great.

But little attention, comparatively, has been paid to the design and construction of small steam-engines until very recently. The engineer has been too often inclined to look upon this as too small a matter to demand the thought and the time that he has freely given to larger and more attractive work. It is now different, and some excellent forms of small engines are to be found in the market. It is the intention of the author here to describe a single example of this class of machine, not as the only good engine of the class, but as a type of this class.

The British builders of portable and agricultural engines were the first to develop the art of steam-engine design and construction in this department. A dozen years ago, they were building engines of as little as 20, or even 10, horse-power, which demanded but 3 pounds, and even less, of coal pei horse-power per hour. As early as 1867, they reached the figure 4.13 pounds;* in 1870, it became 3.73, and, in 1872, the Reading Iron Works built an engine of 20 horse-power which, on trial at Cardiff, required but 2½ pounds of picked coal per hour and per horse-power. This engine had a cut-off valve on the back of the main valve.† Single valve engines have never done as well; but some of them have nearly approached these figures. A consumption of 5 pounds of coal per hour and per horse-power is a

1. Mechanical Engineering at Vienna; Reports on the Vienna Exhibition: R. H. Thurston, Washington, 1878.

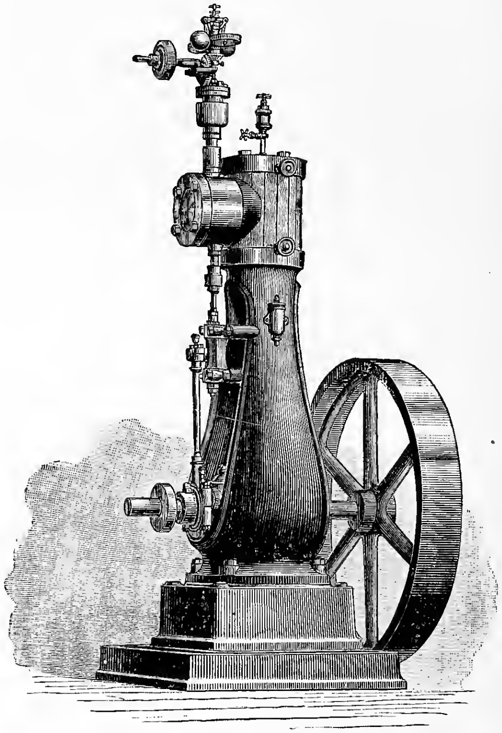
2. Manual of the Steam Engine, Vol. I. § 38.

good figure, and is rarely attained in such small engines. The best of them may be expected to use from 5 to 7 pounds and to consume, therefore, from 40 to 60 pounds of steam, averaging perhaps about 50, on the basis of the indicated power.

Among the earliest of American engineers to turn attention to this department of mechanical engineering, were Messrs. Babcock & Wilcox, who have become well known as the inventors of a successful form of "sectional" steam boiler. The style of engine which was designed and introduced by them, and built by the New York Safety Steam Power Co., has now become as generally accepted as standard among builders of small engines as has the Corliss engine among constructors of drop cut-off engines. It has been copied in all parts of Europe, as well as in the United States. This may be taken as representative of the best methods of construction in this country, and as exhibiting the elegance in proportions, and that excellence of material and workmanship, which are now becoming recognized as desirable in steam-engines of even the smallest size. In fact, as has been seen, the opportunity here offered for improvement, and for economizing steam and fuel consumption, is much greater than with large engines; and these excellencies are, therefore, the more desirable.

The engraving exhibits the form of the engine here to be described. It is a "vertical engine" mounted upon a base-plate of neat and strong form, and with the steam-cylinder bolted by the lower head to a very strong and very graceful frame. The main journals are carried in bearing constructed in the frame, and consequently free from liability to loss

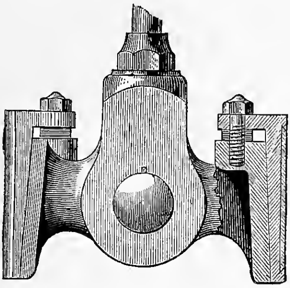
of perfect alignment, or to unequal wear. The valve is either a plain, locomotive-slide, or, preferably, a piston valve. The latter is fitted in a detachable seat, which can be easily removed for renewal of seat and valve, should accident or wear ever make it necessary.



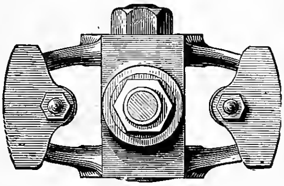
N. Y. Safety Steam Power Co.'s Engine.—5 H. P.

The vertical position of the engine prevents wear within the cylinder becoming serious or unsymmetrical. The pistons are hollow, and are packed with rings set with suf-

ficient spring to keep them up to a bearing. The cross-head, which is shown in the following engraving, has its gibs turned to fit the guides in the frame, which latter are part of the casting of the frame and are bored out in line with the cylinder, and cannot possibly get out of line.



CROSSHEAD.

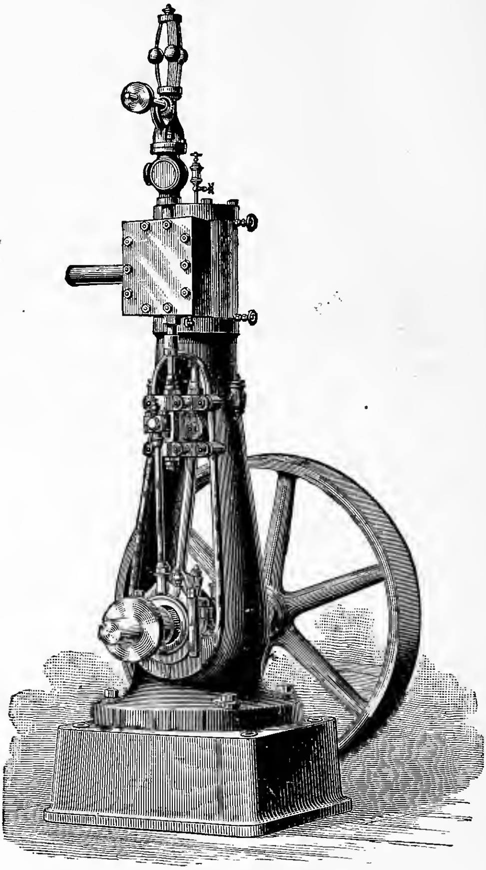


CROSSHEAD.

The engine above illustrated is of small size—4 or 5 horse-power—and has been especially designed for electric lighting purposes. The governor is that known as the "Waters Governor;" it regulates by adjusting the supply of steam passing to the engine through a throttle valve—a method which seems to have been here more successful than is usual in engines having to perform so exacting a kind of work. The speed of this engine is usually about 250 revolutions per minute.

Larger engines of this style are often constructed ranging up to 100 horse-power. The heavy engines, when of 15 to 100 horse-power, are given an independent crank-shaft pillow-block and a counterbalanced disc-crank. In these engines, of all sizes, the modern innovation of the use of steel for running parts is very generally introduced. The rods, pins, and minor parts are of this metal; the bearings

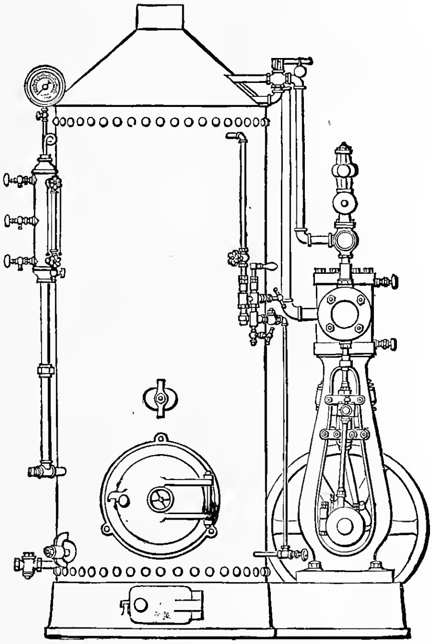
are usually of bronze lined with Babbitt metal, and are given large area. Crank-shafts are either of steel or of



10 H. P. VERTICAL ENGINE.—N. Y. S. S. P. Co.

hammered iron. As is customary with all well constructed engines, these engines are set up and operated in the shop long enough to exhibit all defects and to afford

opportunity to make all adjustments before sending them out, and are thus made safe against those annoying delays which otherwise attend the introduction of such machines. The parts are made to gauge, and therefore interchangeable; and it is thus made easy to replace them when worn or injured, at minimum expense and with little delay The



SEMI-PORTABLE ENGINE.

valves, and their seats, even, when worn, are taken out, sent to the shop, and the spare valve and seat, already fitted, takes the place of the parts removed.

Where engines are of large size, they usually have the engine room and boiler room distinct; with these small engines, however, it is found often to be desirable to place engine and boiler side by side, and even upon a common base, as is illustrated by the last of the preceding engravings. This forms what is known, frequently, as the "semi-portable" engine, to distinguish it from the "portable," which last named style is mounted on wheels.

THE ERICSSON AND WESTINGHOUSE ENGINES.

ALL of the engines which have been considered in the preceding articles are of one general type—that known as the "double-acting reciprocating engine." Before the time of James Watt, the only engine in extended use, even in the limited field in which the steam engine was then employed—that of pumping water from mines—was a "single-acting" engine—the Newcomen engine, which had then almost entirely superseded the so-called engine of Savery. Watt invented, first, the separate condenser, and then the double-acting engine, thus increasing the power of the machine and rendering it, at last, applicable to the turning of a crank and the driving of machinery and mill-work. In the "single-acting engine," the steam drives the piston in but one direction, and the return stroke must be made without the production of useful work. In the "double-acting engine," the steam acts upon the piston in both directions, and with practically equal effect. Thus, a more regular action is secured with a given weight of balance

wheel, or the same regularity with a wheel of one-half the weight of that required for the older form of engine. This smoothness of motion is, in such work as is here considered, one of the most essential features of the best steam engine economy. At the speeds which have been now attained, however, the inertia of moving parts becomes so great that moderate variations in the impelling power become comparatively insignificant, and have no perceivable effect upon the smoothness of revolution of the crank-shaft.

The double-acting engine evidently possessed greater power than its predecessor, when of the same size, and the "efficiency of the machine" was correspondingly increased.

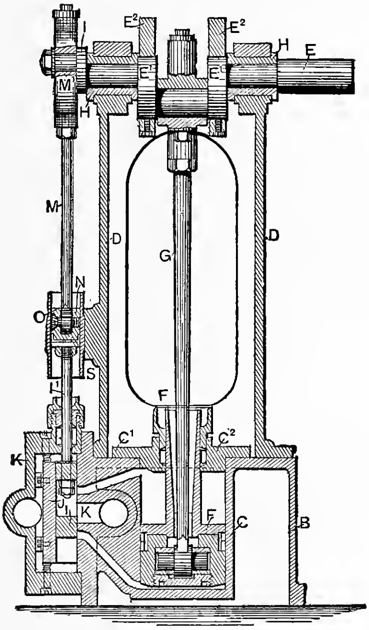
The very conditions which have been thus made to aid in securing regularity have, however, introduced a new difficulty: At every revolution of the engine, the crank "turns the centre" twice; and, at every passage of the centre, the direction of pressure upon the crank-pin is reversed, thus producing a shock which is proportional to the difference of pressure, the suddenness with which it is felt at the pin, and the extent of the "lost motion" between the pin and its bearings. Some lost motion must always be permitted here, to avoid danger of heating of the journal and injury to the machine. The counteracting adjustments are found to be, usually, the utilization of the inertia of the reciprocating parts, as in the Porter-Allen engine; the adoption of heavy compression, as in the several engines afterward described, and very careful adjustment of the fit of the brasses on the pin. With the skilful use of these expedients, and with the introduction of a perfection of workmanship, and of such qualities of material, as have

never before been seen, the "high-speed engine" has been made successful at as high as 400, and even, in some cases. 600 revolutions per minute. The lower of these figures may be taken as that representing the maximum in standard, and usually best, practice.

But much higher speeds than these are sometimes demanded; and engines must, in the future, be built to run, regularly, steadily, and safely, at, probably, very much higher velocities. This may, ultimately, lead to radical changes in the design of the now standard forms of fast engines. Nevertheless, the limit of speed has by no means been reached, even at the higher of the above speeds, with the common type of engine. The speed of even 450 times the cube root of the length of stroke, now a common figure, and three times that given by James Watt's rule, is occasionally greatly exceeded. Captain Ericsson designed an engine, now many years ago, for the electric lighting apparatus of the Delamater Iron Works, which was then kept running, every evening for two or three years, at 1,250 revolutions per minute, without giving the slightest trouble, or meeting with the most insignificant accident. The piston speed is about twice that of the average "high-speed" engine, and six times that adopted by Watt. It is probably the highest speed ever attained by a reciprocating engine. This engine is preserved at Sibley College.

The object of the inventor was to design a steam-engine for the special work of driving small dynamo-electric machines, and hence to secure great stability and strength, a minimum number of parts requiring lubrication, and abso-

lute certainty that the parts retained should be, at all times, thoroughly supplied with the lubricant. The engine is therefore made a "half trunk" engine, the trunk, *F*, *F*, serving as an oil reservoir. The joint in the eccentric rod is provided with a piston moving in a cylindrical guide, *N*, which is also an oil reservoir. The cylinder, *C*, and base-plate, *B*, are in one casting, upon which is set the



THE ERICSSON ENGINE.

hollow frame supporting the crank-shaft, *H*, *E*, and balance wheel. Every journal and rubbing part has an oil reservoir and special provision for effective lubrication. The whole engine is a model of the product of that most efficient kind of ingenuity which seeks definite ends by the most

simple and direct means. This "plant," engine, dynamo, and lamps, is now preserved in Sibley College.

The limits to velocity of piston and speed of rotation have, from the beginning of steam engine practice, been thus gradually set farther and farther back; and one after another of the limiting conditions have been successfully met and overcome. The earliest limit was that found in the bad workmanship and material which Watt and his contemporaries encountered, and which gave rise to heated journals at even what would now be considered very low speeds, and at very small powers. This defect being gradually overcome, the next, and a comparatively modern, difficulty was found in wear, and the "pound," which took place when the lost motion of journals in the line of the connecting rod was taken up, at the passing of the centres. This difficulty was met in two ways, as already repeatedly stated—by making use of the inertia of the reciprocating parts, as was done by Porter and Allen, and by heavy compression as is practiced in nearly, or quite, all of the high speed engines of to-day. The first method can be adopted only when careful proportioning, after calculation, of the weights and velocities of the moving parts, has determined the proper weights of the compensating pieces. The latter adjustment may be made either by calculation or by experimentally finding the compression giving smoothest running. This effect of increasing compression can be most satisfactorily seen in the marine engine, in which, whatever the speed of the machine, and whatever the steam pressure, or however loose the journal, the link may be raised so as to gradually check the

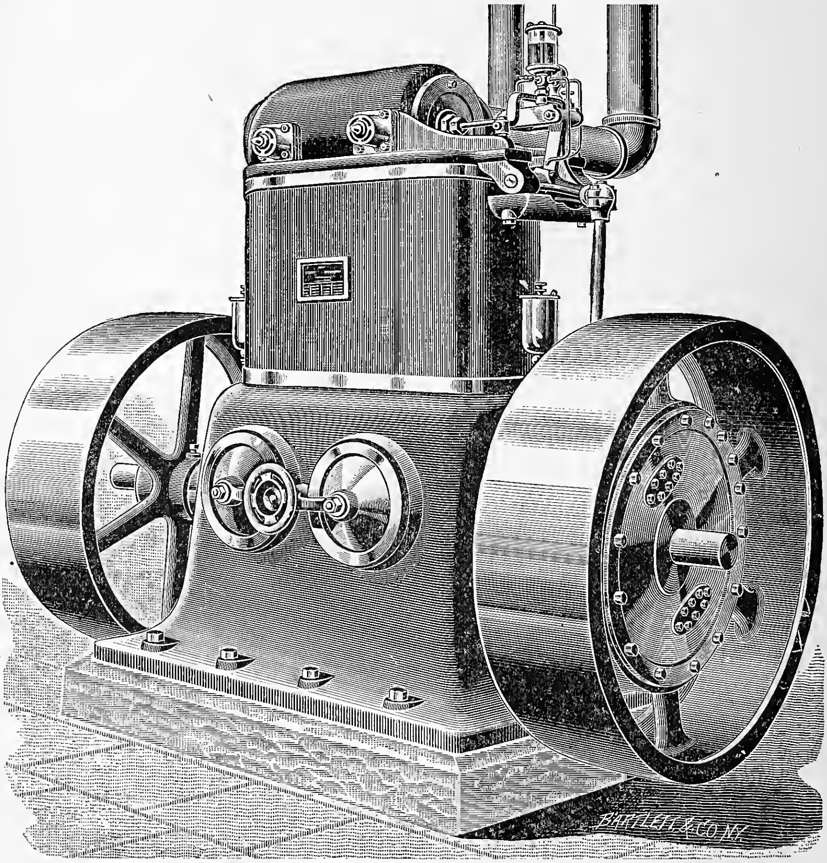
pounding at the centres, and finally to eliminate it altogether, the engine often being thus brought to work silently and smoothly at speeds far above those which, without compression, would be very troublesome, if not absolutely dangerous. This is an experiment which the writer has repeated on many engines, and almost invariably with the same satisfactory result.

Some lost motion must always be permitted at the crank-pin, and these expedients are usually found to meet the case. They probably have their limits, however. There comes a time, as speeds are increased, when the weight of running parts, as calculated for strength only, becomes as great as is desirable to effect the compensation by their inertia ; there comes a time, as compression is increased, when the "cushioned" steam is carried up to boiler pressure, and this would seem the natural limit in this matter. The next device, chronologically, adopted by the engineer, is that of preventing the lift of the brass of the crank-pin and of the cross-head pin at the turning of the centres, while still leaving the freedom of fit required to give safety from heating. This last expedient is that which has led to the construction of a class of engines which are as peculiar and as typical as either of the classes which have been already described.

THE WESTINGHOUSE ENGINE

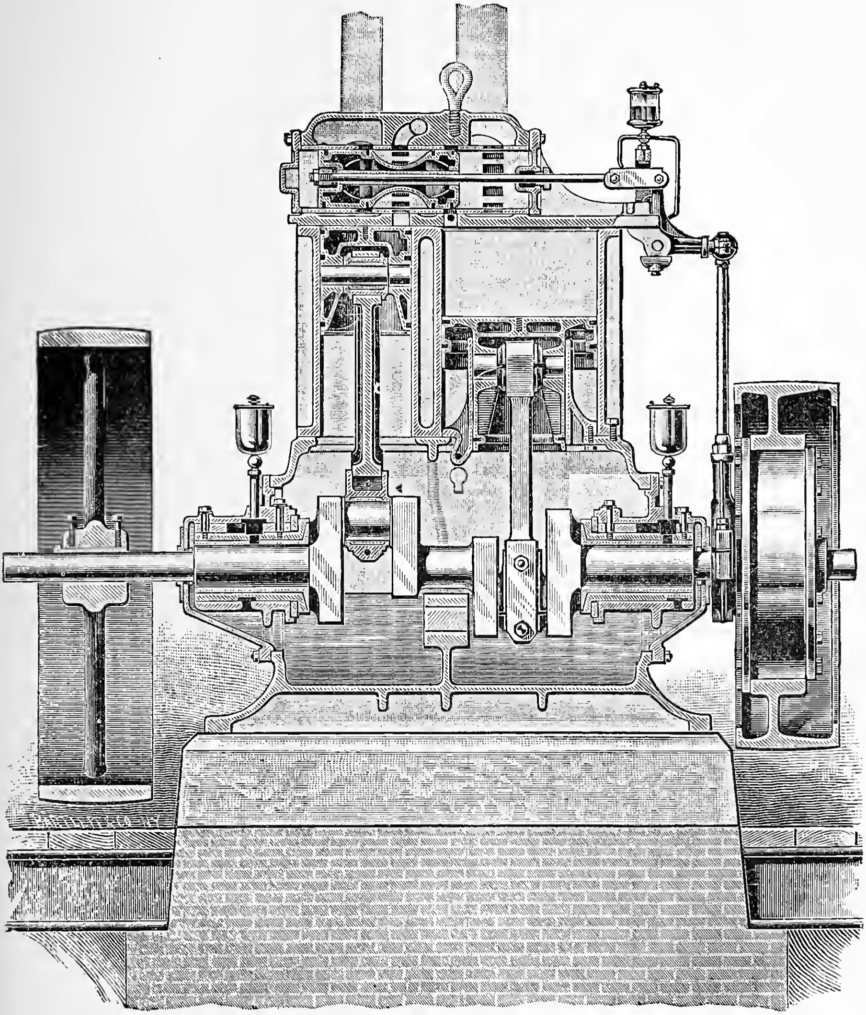
belongs to this new class, and is here taken as its representative. The change of construction characteristic of this type of engine is a return to the original "single-acting" plan of engine. This has been often proposed, and not infrequently attempted ; but the success attained has not, as a rule, been satisfactory. Two, and three, and four, cylin-

ders have been tried, in the endeavor to secure regular motion while taking steam only on one side of the piston ; very

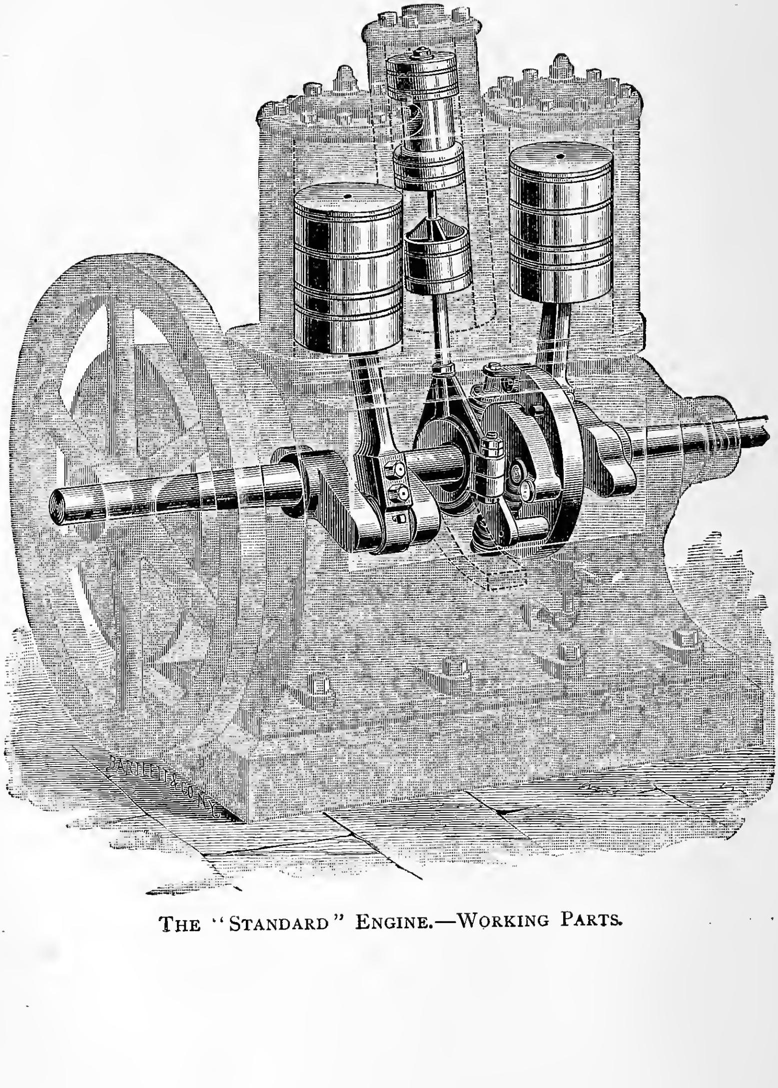


THE WESTINGHOUSE COMPOUND ENGINE.

high speeds of revolution have been attained ; but the cost of steam has been found too great, and their use has not become general. The Westinghouse engine has proved it-



Section of Compound Engine.



THE "STANDARD" ENGINE.—WORKING PARTS.

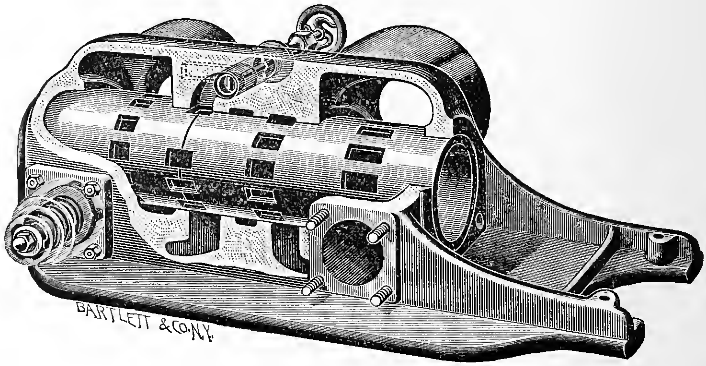
self to possess the elements of commercial success, and is, therefore, to be taken as illustrating what can be done in this direction, by good designing and good business management.

It is evident that, if steam pressure comes upon but one side of the piston, the engine can pass its centre without the brass lifting clear of the pin, and thus may be driven up to any speed without liability of injurious pounding. For high speeds, as the engineer of to-day looks upon them, this is evidently the type of engine to be looked to for smooth and successful working. The illustrations show how, in the Westinghouse engine, this end is reached. The engine has two cylinders fitted with single-acting pistons forming trunks filling the bore of the cylinder, giving a long steam-tight bearing, and taking the connecting-rod pin at a point at which no tendency to rock the piston can be produced. The top of the piston is cored out to prevent transfer of heat from the working to the non-working end. The rods take hold of the crank-pins within an enclosed chamber forming part of the engine frame. This frame and bed-plate also acts as a reservoir for oil lubricating the journals and pistons, which oil floats on water and is dashed up over the moving parts so enclosed, at every revolution of the engine. No other attention is required than to keep a supply of oil in the chamber, by filling as loss occurs by leakage. In fact, the whole engine is thus shut in by its frame, and its working parts are invisible, while working—an arrangement at once a means of security and convenience.

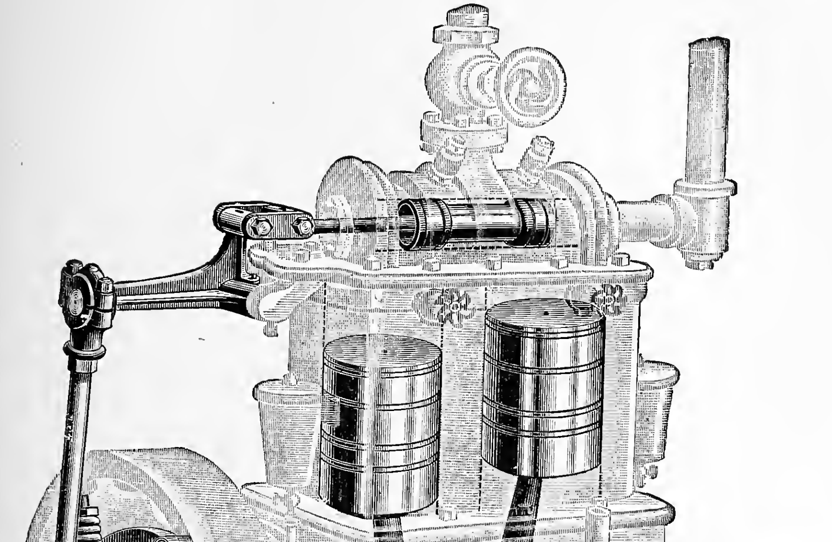
The valve adopted in the Westinghouse engine is a piston

valve of the class already described, but having some peculiarities specially adapting it to its use in this engine.

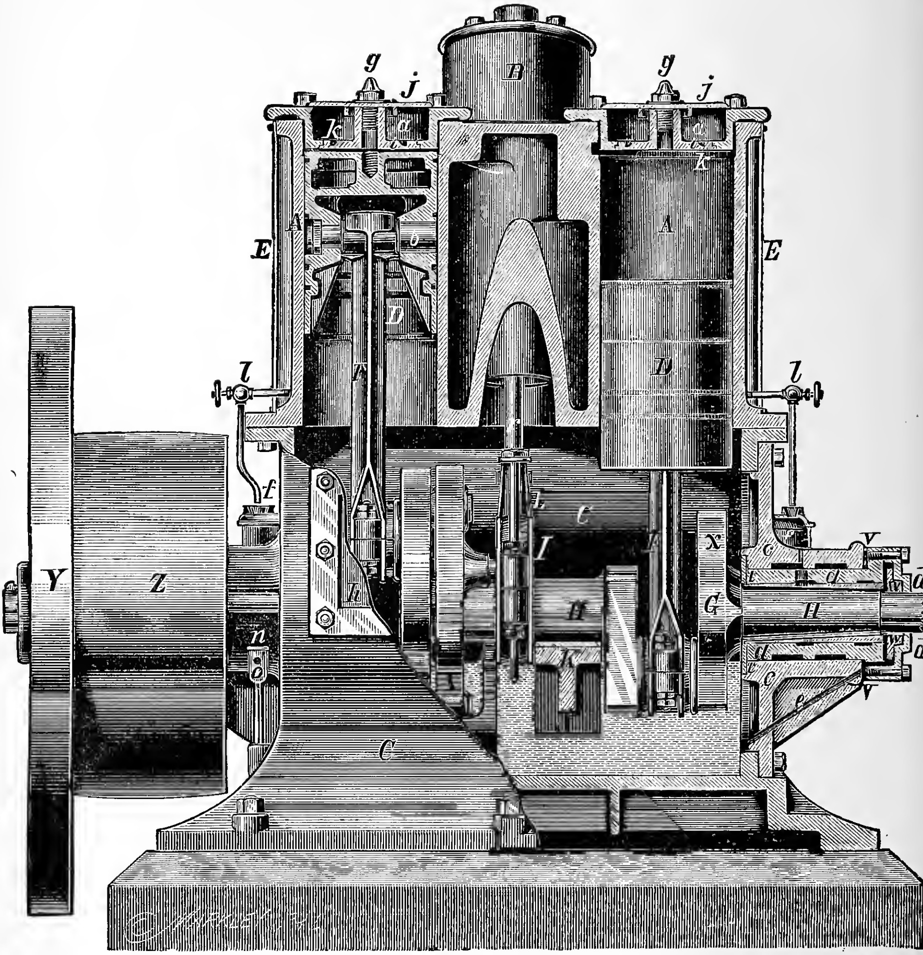
A single piston-valve distributes steam to both cylinders, securing, at the same time, some special advantages, and illustrating ingenious adaptations to this singular and ingenious type of engine. The accompanying engravings exhibit the forms of the three designs of this machine in common use: the "Standard," the "Junior," and the Compound. In the first, the valve is placed in the vertical plane; in the others it lies along the top of the two cylinders. The essential features of the three engines are very similar, and equally characteristic. To insure freedom from danger from water entering the cylinders, the great source of risk with high-speed engines, relief valves are fitted to all, and are illustrated, in the perspective drawing, at either end of the valve chest. It is still better shown in the accompanying sketch of the valve chest employed in the compound engine, which also exhibits the internal construc-



VALVE CHEST.



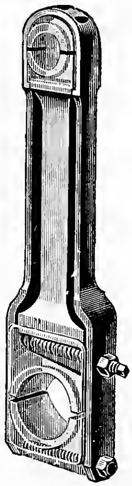
THE "JUNIOR" ENGINE.



THE WESTINGHOUSE ENGINE.—SECTION THROUGH SHAFT.

tion of the chest and the location of ports, by-pass, and fittings.

The main valve, thus fitted, is easy of access and of removal or replacement; the crank-case shuts in the lubricating fluid, a mixture of oil and water, and allows the splashing action of the cranks to insure thorough and unintermitted lubrication, with flooded journals; and, at the same time, the accident of piston leakage, should it occur, is immediately revealed by the exit of steam from the vapor pipe. Leakage at the valve is detected by removing the valve-chest bonnet cover, and working the engine in that condition. Access to the crank-case is obtained by removing the bonnets seen in the perspective drawing of the engine. Since this engine is especially designed for high speeds of rotation, the necessity for insuring permanence of action and durability by positively certain lubrication is vital. The construction of the connecting rod, as seen in the next figure, illustrates one of the adaptations of details of construction to this exigency.



CONNECTING ROD.

The rod consists of a body and two boxes, with a take-up wedge between the body and the top of the lower box. Both the upper and lower boxes are in halves, made of hard brass, babbitted. A continuous strap has its ends bolted to the lower half-box and runs around the upper, binding the whole together. Tightening up on the wedge-bolt will expand the rod lengthwise, and take up both ends alike, and to any

desired adjustment. The strap transmits no strains. This, as many other parts of these machines, has been designed with a view to securing safety in continuous rapid working, while retaining low cost of construction in manufacturing in quantities. The makers report one case in which one of these engines, of ten horse power, was in continuous operation thirteen months and eight days, at a speed of 500 revolutions per minute. Such speeds as these are found useful in securing direct connection and its attendant advantages, in driving electric light and power machinery; and the makers of these, like those of a number of other engines of the older type, are making this application with success. In some locations, as on shipboard, this arrangement is almost obligatory; where practicable, it is probably usually desirable.

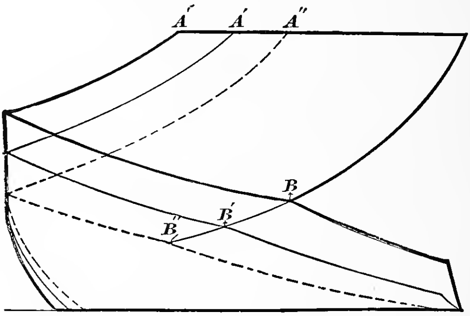
The governor of these engines, shown well in the last of the sketches of the machine, is similar in principle to those already illustrated in the previously given accounts of the high-speed engines of other forms. It is a "shaft governor," directly acting upon the valve stem and determining the momentary range of expansion. It illustrates more clearly than do the engravings already given, however, the following principle, which may often be utilized in a properly designed governor of this class: It will be observed that the balls are here weights of elongated form, reaching across the line of the shaft, and so set that any sudden jump of the engine, whether in acceleration or in retardation of its speed, will tend to carry the shaft past its momentary relation of angular position relatively to the balls, and thus to, in the one case, increase the ratio of expan-

sion, and, in the other, throw the valve into a position for "following further," supplying more steam and doing more work; while the instantaneous action thus secured insures as instantaneous adjustment of the steam-supply to the load, irrespective of the action of the centrifugal force of the balls. The most perfect governors of this type have been known to hold the speed constant, within a fraction of one per cent., not only as an average, but even preventing that jerk and oscillation, when, as by breaking the circuit of an electric lighting system, or restoring contact, the load is instantly completely thrown on or off, which is commonly both noticeable and objectionable with less efficient governors. This action of the "inertia governor" is peculiarly valuable in such work. It is obtained, in this case, by making the paths of the center of gravity of the governor balls traverse the radial line between the center of suspension of the arm and the shaft-center, as nearly as possible at right angles, and as near the pivot as practicable. Experience shows that, in a successful governor of this kind, it is possible to make the fluctuations of speeds entirely insensible, whatever the extent or rapidity of the changes of load. The centrifugal element maintains the mean speed of successive strokes with precision, and the inertia element insures it against sudden surges.

The cranks of these engines are set opposite each other, and thus a balance of reciprocating parts is secured which gives freedom from jar and from inconvenient or dangerous shaking of the engine and its foundations. The ingenious and novel methods of securing certainty of lubrication; the constant direction of forces tending to produce heavy

strains; the small number of parts; the reduced labor of attendance; the compactness, solidity, steadiness, safety at maximum speeds, and general effectiveness are such as to make it one of the most interesting of all the modern forms of steam-engine.

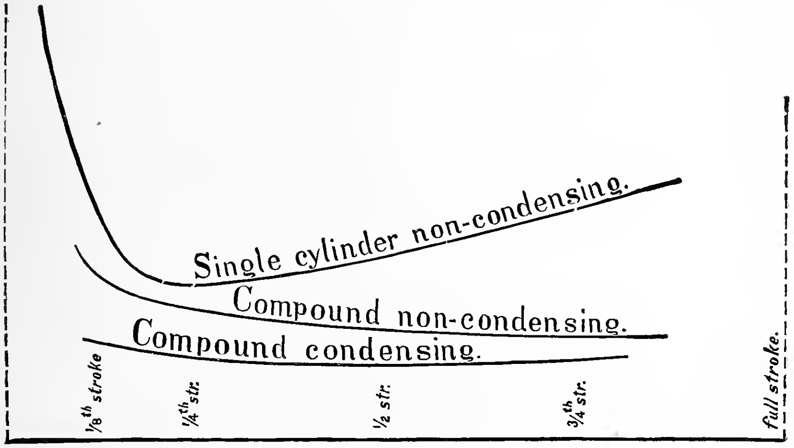
The forms of simple engine illustrated in the described figure and the last engraving of this series, by a natural process of evolution, developed into the compound engine shown in the first two engravings; the one cylinder being made properly proportioned to the other, and the steam dis-



WESTINGHOUSE COMPOUND ENGINE DIAGRAM.

tribution being effected by the same valve, as shown; the steam rejected from the smaller engine being passed into the larger, and thence into the condenser or into the atmosphere. The principles of the compound engine will be discussed in the next chapter; but a peculiarity of this type may be best described here. The indicator diagram produced by the engine is very nearly that shown in the accompanying figure. By giving the intermediate chamber or receiver, which here becomes a clearance space for the

small cylinder, a volume having the same proportion to the small cylinder that the volume of the latter bears to the large cylinder, with several ingenious and effective corrections for minor variations of kinematic and thermal movement, the single valve is made to give precisely the distribution desired: such that the expansion in the small cylinder from any point, *A*, and into the larger, up to the cut-off of the latter, will always give a terminal, at *B*, such that the compression in the small cylinder will carry the line up to boiler pressure. The action of the low pressure compres-



ECONOMY UNDER VARYING LOADS.

sion completes the diagram in singularly admirable form, and, incidentally, aids by reducing the liability to wastes by internal condensation. The curious result is thus reached that the total range of temperatures and pressures and their division between the two cylinders remain nearly constant, whatever the load on the engine; and the machine is thus

caused to adapt itself comparatively perfectly to all loads, and to vary comparatively little in its efficiency, and this with a single valve and the simplest of mechanism. This result is illustrated by the accompanying diagram, which the makers give as the result of their experience with the variations of economy of the three classes of engine with varying loads and correspondingly varying expansions, and by the following figures:

WATER RATES, BY TEST, UNDER VARYING LOADS.

Horse-Power.	210	170	140	115	100	80	50
Non-condensing ..	22.6	21.9	22.2	22.2	22.4	24.6	28.8
Condensing	18.4	18.1	18.2	18.2	18.3	18.3	20.4

VI.

Multiple-cylinder Engines; Proportions of Parts.

WE have now made a tolerably complete survey of the whole modern field of steam engineering as far as it is covered by our earlier practice, and have seen a very steady progress from the best types of a generation ago to the most representative examples of the later simple forms It is seen that the direction of change is still that which, as has been often pointed out by the author, has been observed from the days of James Watt. The principal points found worthy of notice have been the increase in economy and general efficiency by a tentative and empirical, but none the less steady and uninterrupted, method of advance. The pressures of steam have been slowly, but constantly, rising; speeds of piston, and of rotation, have been as constantly increasing; the effectiveness of the governor has been made greater and greater; the ratio of expansion at maximum efficiency has been very slowly increased, by the gradual reduction of "cylinder-condensation;" commercial considerations have been brought definitely into view; the efficiency of engine has been improved by reduction of size, weight, and friction of engine; and thus we have been able to see a gradual change of type of engine effected, the engineer modifying his designs to meet the demands of the time, until we have insensibly, and almost without suspecting that progress has been going on, passed across a new line and entered upon an epoch, in steam-engine construction, as marked in its period and as well defined, as to its

beginning, as was that which, at the middle of the century, was distinguished by the introduction of the inventions of Sickles, Corliss, and Greene.

The latest phase of this progress is to-day witnessed in the rapid introduction of the multiple engine in all departments of electric work. There has been made, recently, a more careful study of the relative merits of the older "drop cut-off" engines and the modern "high-speed" type. This has led to the careful discrimination of the conditions under which each form of engine is advisable. The former, as constructed by the best makers, commonly excels in economy; the latter excels in compactness, cheapness, and in nicety of regulation. Where large power of uniform amount is demanded for considerable periods, without fluctuation or intermission, the older type is often the better; but, when the work is variable in amount, called for in irregular and uncertain periods, and capable at the same time of being divided among several engines, the later type is very generally advised. Thus it happens that both types of engine find constant employment and an increasing market.

The most striking feature of current change is the introduction of the multiple engine, and in both of these two principal classes of engine. A very large number of these engines with detachable valve-gear may now be seen at work where large "plants" are in operation, and nearly every builder of the "high-speed automatic" engine is now "compounding" or preparing to compound his machine. The method and the serious importance of the wastes occurring in all heat-engines, in consequence of the impracti-

cability of constructing their working cylinders of a non-conducting substance, have already been stated.[1]

The unavoidable thermodynamic waste is rarely less than seventy-five or eighty per cent., and the internal wastes by conduction and storage, with subsequent rejection, by cylinder or internal condensation, as it is customarily called, and by leakage, range from ten per cent., as a minimum, perhaps, to twenty-five or thirty per cent., in good engines; to fifty per cent. in many cases, and even to much more than the latter proportion in exceptional cases. It is this which constitutes, ordinarily, the great source of loss and inefficiency of the real, as distinguished from the ideal, engine.

THE AMELIORATION OF WASTES thus becomes an important matter.[2] The three methods which have been found advantageous, and, in special cases, fairly effective, are:

(1.) Superheating ;

(2.) Steam jacketing ;

(3.) "Compounding."

It is evident that, if the steam can be introduced into the engine at such a temperature that the cooling action of the metal of the cylinder will not cause its condensation initially, and the stroke may be performed without condensation in consequence of doing work, no loss of heat from the cylinder can take place by re-evaporation; and if no such loss occurs, the waste of heat at entrance, in turn, by initial cooling, will be reduced. Superheated steam, also, is a

1. Chapter II., p. 9.

2. This portion of this chapter is mainly condensed from a paper by the author, read before the American Society of Mechanical Engineers, November, 1889.

non-conductor and a non-absorbent of heat, precisely like the permanent gases. It is thus, also, less liable to this waste. But it is found in practice that superheating beyond a very moderate degree, perhaps 100 to 150 degrees Fahrenheit, is inadvisable on account of risks of injury to engines and cost of repairs to superheater, which more than compensate its advantages.

Steam-jacketing is another and a common partial remedy for this waste. By surrounding the steam-cylinder with the steam-jacket, it is possible to produce, in part, the effect of superheating; that is, to secure dryer steam in the engine throughout the stroke. The amount of re-evaporation, during the period succeeding cut-off and up to the closure of the exhaust-valve, and the quantity of heat of which the cylinder is thus robbed, measures the amount of initial condensation and waste, and the weight of steam which must be supplied in excess of the thermodynamic demand to compensate that loss. The effect of the addition of a steam-jacket depends upon the conditions of operation of the engines, largely, and may be productive of marked advantage, or, under unfavorable conditions, of no important useful effect. High-speed engines derive less advantage from its application than slow-moving machines; and compound, or multi-cylinder, engines are less dependent upon it for economy than are simple engines. The addition of this expedient, if properly performed, appreciably increases the magnitude of the ratio of expansion at maximum efficiency of fluid. The assumption is commonly made that the superheating is retained throughout the stroke, and that steam-jacketing may be relied upon to keep the working

charge dry and saturated throughout the stroke; but neither of these hypotheses, as employed in the theory of the engine, is probably, as a rule, practically correct.

"*Compounding*," or the use of the multiple-cylinder engine, in which the steam exhausted from one cylinder is again worked in a succeeding one, is the most familiar of devices for extending the economical range of expansion and increasing the efficiency of the engine. The limit to the useful extension of the expansion of steam in a single cylinder is found to be determined by the magnitude of the wastes incurred in the operation of an engine of which the working cylinder is a good conducting material. Any method of reducing this waste of heat internally will enable the efficiency of the engine to be increased by further profitable extension of the ratio of expansion. Common experience with the best constructions, and considerations which need not be here reviewed, show that the engineer may reasonably expect, by good design, construction, and management, to secure an economy of steam which is fairly measured by the following table, the ratios of expansion, r, taken being, for each case, those which give best results for a given engine, engines of fair size being taken :[1]

STEAM PER HORSE-POWER PER HOUR,

At best ratios of expansion in best engines.

r	3	4	5	6	7	8	10	12	15	20	25	50	75
lbs.	32	27	25	22	20	20	19	17	16	14	14	11	9
kgs.	15	12	11	11	9	9	9	8	6	6	6	5	4

1. Several Efficiencies of the Steam Engine; Trans. A. S. M. E., and Jour. Franklin Inst., 1882.

and ten per cent. better figures than these have been actually reported in peculiarly favorable cases.

Assuming it to be possible to divide the waste by cylinder condensation and leakage by two or more, it is evident that the limit to economical expansion and transformation of heat into work will be set correspondingly further away. This is precisely what is done by the multi-cylinder engine. The internal wastes are reduced approximately to those of the most wasteful single cylinder, and the gross percentage of waste is made less in the proportion of this division. The heat and steam rejected as waste by internal transfer without transformation from the first cylinder, is utilized in the second nearly as effectively as if it were received directly from a boiler at the pressure of rejection from the first cylinder. Insomuch, therefore, as the pressure can be increased and the increase utilized by the addition of another cylinder, gain is secured.

The practical questions thus meet the engineer: To what extent can this principle be availed of? what range of pressure and what ratio of expansion should be assigned to a single cylinder? and how many cylinders should be adopted to give best results with the highest steam pressure practicable for a specified case? Common experience aids in solving this problem by showing that the very best results are ordinarily obtained, in each class of multi-cylinder engine, when, the engine being properly designed for its work, terminal pressure for the system can be economically made something above the sum of back pressure in the low-pressure cylinder, plus friction of engine. This total may be usually taken as a maximum, probably, at

about eight or ten pounds above a vacuum. The latter figure will be here assumed.

THE FUNDAMENTAL PRINCIPLES are now easily perceived. There are three main facts upon which to base our theory of the multi-cylinder engine. These are :

(1.) *Economical expansion in a single cylinder has a limit, due to increasing internal wastes, which is found at a comparatively low ratio of expansion.*

(2.) *The method of expansion may be, for practical purposes such as are here in view, taken to be approximately hyperbolic ; the terminal pressure being something above that which corresponds to the sum of all useless resistances, and which may be here taken, as, for example, about ten pounds per square inch above a vacuum. The division of the initial pressure by this terminal pressure will thus give an approximate measure of the* desirable *ratio of total expansion for the best existing engines.*

(3.) *All steam entering any one cylinder will be rejected,* as steam,[1] *into the succeeding cylinder, external wastes being neglected, and into the condenser ; and the full amount of steam condensed at entrance by absorption of heat by the interior surfaces of the cylinder will be re-evaporated later, and will pass into the condenser or into the next cylinder ; and heat transferred in the one direction, in the one process, will be transferred in precisely equal amount in the opposite direction in the other.*

This last point is a very important one, and is very easily established. The cylinder, when in steady operation, is

1. This the author would denominate Hirn's principle. See a paper by M. Dwelshauvers-Déry in the *Bulletin de la Société Industrielle de Mulhouse*, October, 1888, on the theory of single-cylinder engine.

neither permanently heated nor permanently cooled; no progressive heating can go on, as it would, in that case, become heated above the temperature of the steam and become a superheater; no progressive cooling can occur, since, in that case, the cylinder would become a condenser of indefinite capacity. It must, therefore, transfer to the next element of the system all the heat which it receives, assuming that external radiation and conduction may be neglected, and that the Rankine and Clausius phenomenon of internal condensation, by transformation of heat into work, is ignored. It also further follows that the introduction of one or of many cylinders between the terminal element and the boiler does not, through cylinder-condensation alone, affect the operation of the latter cylinder, however great that condensation may be; provided the operation of the added elements is effected by raising the steam pressure commensurately, leaving the final element of the series the same initial pressure as before. The total waste by this form of loss is thus evidently measured, in the case of the multi-cylinder engine, by the maximum waste in any one cylinder. If all are equally subject to this loss, the rejected steam of re-evaporation from any one cylinder, as the high-pressure cylinder, supplies precisely what is needed to meet the waste by initial condensation in the next; and so on through the series. Thus the use of a series of cylinders, in this manner, divides the total waste for a single cylinder, approximately, at least, by the number of cylinders; and it is in this manner that the compound system gives its remarkable increase of efficiency. As stated by the author, many years ago, "The serious losses arising from condensation

and re-evaporation within the cylinder, and which place an early limit to the benefit derivable from expansion, affect both types of engine, and so far as seems now known, equally;"[1] but the compound type permits the interception of the heat wasted from one cylinder, for utilization by its successor, in such manner that the total waste becomes, practically, that of the low-pressure cylinder alone. If any one cylinder wastes more than another, the total waste is, as above stated, measured more nearly by the loss in the most wasteful member of the system.

Thus the three principles which have been above enunciated give a means of constructing a philosophy of the multi-cylinder engine, which will meet the essential needs of the designer and of the student of its theory. The first principle shows that, a limit existing to economical expansion in a single cylinder, the advisable number of cylinders in series may probably be determined, when that limit is ascertained, either by experiment, by general experience, or by rational theory and computation. The second principle shows that we may find a tentative measure, at least, of the desirable total ratio of expansion for maximum efficiency, when the best terminal pressure for the chosen type of engine is settled upon. This total range is divided by the admissible range for a single cylinder; or, perhaps better stated, the total ratio is a quantity which should approximately equal the admissible ratio for a single cylinder, raised to a power denoted by the number of cylinders. Combining thus the two considerations referred to, we obtain a determination, probably fairly approximate, of the proper number of cylin-

1. Vienna Report, 1873.

ders in series. The third principle permits an estimate to be made of the probable internal wastes of the series, and the probable total expenditure of heat and of steam, and a solution of all problems of efficiency for the compound engine, of whatever type.

The first step in the process is evidently the determination of the best ratio of expansion, under the assumed conditions of operation and for the given type of engine, for a single cylinder; then the best ratio of expansion for the series, all things considered; this study being made from the financial standpoint, as must be every problem which the engineer is called upon to solve. It is not the thermodynamic, nor the fluid, nor even the engine, efficiency, which must be finally allowed to fix the best ratio of expansion; but it must be the ratio of expansion at maximum commercial efficiency; that which will make the cost of operation at the desired power a minimum for the life of the system.[1] The total ratio being settled upon, and that allowable, as a maximum, for the single cylinder, it is at once easy to determine the best number of cylinders in series. The first-mentioned ratio is that at maximum commercial efficiency, as just stated; but the second must be taken as that which gives the highest efficiency of engine; the back-pressure in that cylinder, and the friction of the cylinder, taken singly, being considered, together with its proper proportion of the friction of the engine as a whole.

The extent to which expansion may be economically carried in a single cylinder will vary somewhat with the initial

1. See papers by the author, on the efficiencies of engines, as per references already given; and Manual of the Steam Engine, Vol. I., Chap. VII.

temperature and pressure, and with the physical condition of the working fluid; but it may be taken as ordinarily not less than two-and-a-half expansions for unjacketed engines with wet steam, and three or four for the better class of engines. The total expansion ratio thus becomes, for several types of multi-cylinder engines, as below:

MULTI-CYLINDER ENGINES.

No. cyls.	1	2	3	4
r	2.5 to 3	6.25 to 9	16 to 27	40 to 81
p_1	25 to 30 lbs.	60 to 100 lbs.	120 to 300 lbs.	350 to 800 lbs.

Expansion is here assumed to be approximately hyperbolic, and the terminal pressure to be eight or ten pounds per square inch. General experience to date thus indicates that a triple expansion engine should do best work up to a pressure of about $p_1 = 150$ to 250 pounds, and that the four-cylinder engine should be adopted from that point up to the highest pressures likely to be adopted in the steam engine, the double expansion compound serving its purpose well below the lowest figures above assigned to the triple engine. Any of the four types of engine may be made to overlap the range assigned that case by suitably providing against wastes occurring within the engine by increased speed, by superheating, by expedients giving higher effectiveness to the jackets, or other methods of improvement. Any system which increases the efficiency of the simple engine will improve the efficiency of the compound, and will correspondingly increase the range of pressure through which it will give satisfactory gain as compared with the former.

The influence of the several economical expedients rec-

ognized as useful in other forms of engine, such as superheating, jacketing, and high speed of engine, may readily be perceived when the method of operation of the multicylinder engine is understood in its relations to heat-transfer and heat-transformation. We may consider them in their order :—

SUPERHEATING the steam transferred from boiler to engine results in the supply of a fluid which may surrender a certain portion of heat, measured by the product of its specific heat as a gas into the range of superheating and into its weight, to the metal of the working cylinder without the production of initial condensation. If this quantity is equal to or greater than the loss of heat during expansion and exhaust, there will be no initial condensation, and the waste from the high-pressure cylinder will be nearly that due to the passage of a gas through it under similar conditions of temperature and expansion, a comparatively small quantity, since any substance in the gaseous state possesses low conductivity and slight power of absorption and storage of heat. Should the superheating be in excess of this amount, the steam will not begin to condense until a later period, perhaps not at all, the only demand being now for heat to supply the amount required to keep the steam dry and saturated while expanding and doing work. If the superheating be less than the first-mentioned quantity, initial condensation will be reduced, but not entirely prevented. In any case, the quantity of heat represented by the superheating will be a gauge of the amelioration of wastes by internal transfer of heat in every cylinder of the series. The steam leaving the high-pressure cylinder

will be to that extent dryer than it would otherwise be; and this will be true of the succeeding cylinder or cylinders.

Were there no other disappearance of heat than that due to cylinder condensation, superheating at the first of the series would give superheating at each of the others. In so far as condensation doing work, such as was pointed out by Rankine and Clausius, takes effect, and so far as other wastes by transfer without transformation occur, to that extent will the gain, as observed in successive passages from cylinder to cylinder, be reduced; though the improvement of the working conditions above asserted will be none the less real. Each cylinder will have wetter steam than the preceding, in proportion as the condensation doing work and the losses by conduction and radiation increase, as a total, cylinder by cylinder.

STEAM JACKETING, the expedient devised by James Watt, for the very purpose of reducing wastes by internal condensation, a phenomenon of which he was the discoverer, is a method of approximately "keeping the cylinder as hot as the steam which enters it," as Watt put it, in order that no such chilling of the entering steam may occur. We are interested in the answer to the question: To what extent and in what manner is the jacket advantageous in the compound or multi-cylinder engine? Authorities disagree, even where they have themselves had large practical experience. It is sometimes advised to jacket only the high-pressure cylinder; sometimes to jacket only the low-pressure cylinder, and sometimes to jacket the whole series, whether one, two, or three or more. The philosophy of the multi-cylin-

der engine, as above outlined, would obviously indicate that, to secure maximum good effect, assuming the jacket on the whole desirable at all, the best system is the latter, and that, since the waste of the engine is measured by the waste of its most wasteful member, to omit the jacket from any one cylinder insures that the aggregate loss of heat in the whole engine will be increased by just the amount by which waste is increased in that one cylinder by such omission.

It is readily seen, however, that, to secure maximum efficiency, it is as essential to jacket the cylinders of the compounded engine as that of the simple engine. The question which actually arises in practice, for the designing engineer, is whether it will *pay* to jacket at all or not. It can at once be seen that it is not as important, in a financial sense, that the multi-cylinder engine be jacketed as it is to jacket a simple engine of similar range of expansion. The value of the waste due to omission of the jacket is less as the number of cylinders is the greater, and is the less on any one cylinder as the expansion in that cylinder is a less proportion of the whole. It is also seen that those conditions which may make it undesirable, as a matter of finance, to jacket the simple cylinder, make it still less desirable in the compound or multi-cylinder engine. As piston speeds are increased, for example, the necessity of the jacket decreases and the limit at which it will pay to dispense with it is sooner reached in the multi-cylinder than in the single-cylinder engine. It is this principle which justifies the now not uncommon practice of omitting jackets from marine engines which are driven up to

1,000 feet a minute; while pumping engines, in which the speed is always very low, must usually be jacketed if high duty is demanded.

HIGH ENGINE-SPEED, the most modern device for reducing internal wastes, as well as for decreasing costs of engine construction and weights of machine, is evidently a matter of less serious importance as the number of cylinders is increased; yet it is equally evident that, to secure maximum efficiency, it is essential that the time of exposure to the action of the wasteful influences in any one cylinder be made a minimum. At modern and customary speeds of piston and of rotation, the value of this, as well as the other expedients for improving performance, is much less than formerly.

NON-CONDUCTING CYLINDERS, such as were partly secured by Smeaton by the use of his wood-lined pistons and heads, and such as have since been sought by Emery and others; such as was shown to be needed by Watt, and later more conclusively by Rankine and his successors; would do away with the necessity of compounding on the ground of thermodynamic gain; but would leave the advantages of the multi-cylinder engine, on the score of better division of stresses and work, unaffected. What may be done in this direction, it is as yet impossible to judge; but it is not likely that the device of Smeaton can be made successful at modern temperatures and pressures, or in presence of superheating; the plan of Emery of using glass, enamel, or other superficial covering of the exposed surfaces, has not yet given promise of success, and nothing as yet tried seems to give promise of meeting the requirements

of the case.[1] The value of even an approximately non-conducting covering of such nature would be considerable for the compound engine, and very great for the simple engine; especially for the smaller sizes in which the proportion of exposed surface is comparatively large.

Conclusions would thus seem justified as follow: Under similarly favorable conditions we may, with equal likelihood, anticipate a probability that we may obtain better work with multi-cylinder engines in somewhere about the following proportion for good examples:

Engine.		Steam Consumption. Small Engines.	Large Engines.	Gain, Total.	Gain, Diff.
Simple 1-cylinder	Per I. H. P.	40 lbs. per hr.	20 lbs.	..	..
Compound (double expansion).		30	16	20%	20%
Triple expansion..............		20	14	30	10
Quadruple expansion...........		18	12	40	10
Quintuple expansion...........		16	11	50	10

The first three cases are based upon what is probably ample experience; the last two are obtained by inference from the rate of progression thus established, checked by computation, assuming that the loss is reduced in proportion, approximately, to the number of cylinders in series. The probable cost of adding one and another cylinder to any given type is easily ascertained by the engineer; he knows the cost of fuel and oil; the value of capital is as easily ascertained; and he can then readily determine whether the gain fairly to be anticipated is sufficient to

1. The author has recently secured an invention devised by himself, consisting in the solution of the exposed metal surfaces, leaving the carbon of the casting to form a layer resembling vulcanized rubber, which is to be saturated by drying oils, solutions of gum or other non-conductor, the covering so formed being integral with the cylinder-head or other part.

compensate the cost of its acquirement and to give a fair margin of profit.

Another important inference from what has preceded is that the question of use of one or another type of multi-cylinder engine is not primarily settled by the magnitude of the *steam pressure* to be adopted; although it is well settled by experience and by the financial aspect of the question, as just indicated, that it will not pay to compound a machine working at very low pressures; nor to adopt a third cylinder until the pressure approaches, perhaps, four or five atmospheres, the advisability of adding cylinder after cylinder being measured by the rise in pressure, at the rate of not more than one cylinder for each four or five atmospheres pressures. Whatever the pressure, however, the compounding will divide the total thermal loss by internal wastes, approximately, by the number in series; but it does not at all follow that the efficiency of engine or the commercial efficiency will be reduced in similar ratio. On the contrary, it will never pay to carry the complication as far as the study of the ideal case would dictate. The discrepancy will be found to be the greater as the real engine the more closely approaches ideal perfection, the simple engine becoming the more desirable type as the efficiency of it and of each of the several elements of the compound engine becomes greater.

As respects size, it is now easily seen that the gain by compounding is, so far as the considerations here studied are concerned, at least, likely to prove even more marked with small than with large engines; although it may not be, commercially, as desirable to adopt this complication. As the wastes are invariably, under similar working conditions,

greater as size decreases, the desirability of reducing the magnitude of those losses would seem likely ordinarily to be made the greater, also, as size of engine diminishes. With equally dry steam from the boiler, the moisture in the steam and the losses by internal condensation are the larger as the power supplied and the magnitude of the engine furnishing it become less. That experience is showing this to be the fact is evidenced by the steady progress made by builders of small engines in the introduction of the compound engine into the market. In the case of the adaptation of this system to small engines, the effect of cylinder condensation remains in each cylinder, well marked, ordinarily, as is seen in the hitherto unnoticed effect observable where such small engines are constructed of the Wolff type; and the first effect of the cooling action of the metal upon the entering steam is shown by the sudden drop of pressure between the two cylinders, at the moment of opening communication, the fall being like that seen when exhaust occurs into the atmosphere from a high terminal expansion, and amounting, often, to several pounds.[1]

Problems relating to the efficiency of the multi-cylinder engines may be solved most simply by the processes devised by the author in modification of the method of Rankine, originally applied to the study of the ratio of expansion at highest efficiency of capital.[2] The number of cylinders or of grades of expansion being in all such cases settled by general experience and the judgment of the de-

1. This has been noticed and provided for by the designers of the familiar type of single-acting compound.

2. See Manual of the Steam Engine, Vol. I., Chap. VII.

signing engineer, the best ratio of expansion and the best proportions of cylinders are readily determined for any given case by first obtaining the true Curve of Efficiency for the given class of engines, and then, knowing the probable back-pressure to be met with, either by custom or by taking it with reference to the best relation of initial to final pressure, and computing the constant and variable costs of operation, solving the problems, in their proper order, by a graphical construction which the author has shown to be easy and accurately made.[1] It is enough to say here that these best ratios will often be found, for the better class of engines employing dry or slightly moist steam, to be not far from one-half the ratio of initial to back-pressure, the latter including the friction of engine ; and for those of the very highest class, using thoroughly dry or superheated and re-heated steam, on the system adopted by Cowper, Corliss, and Leavitt, this best ratio may be raised economically, on the whole, to about two-thirds the ratio of initial to back-pressure.

It is safer, however, to endeavor to find the real curve of efficiency for the class of engine considered, and use that curve in the solution of the problems of the efficiency of fluid, of efficiency of engine, and of efficiency of plant. It thus becomes easy to ascertain the best ratios for highest duty, for best financial results as designed, as for best commercial returns should the opportunity offer of utilizing more power than is at first anticipated.

PROPORTIONS OF CYLINDERS AND RELATIVE RATIOS OF

1. The Several Efficiencies of the Steam Engine. Jour. Franklin Institute, May, 1882.

EXPANSION in the several cylinders of the multi-cylinder engine may readily be settled when the total ratio and the total power demanded are determined and exactly prescribed. It will be found that the total ratio will be made, usually, not far from equality in the several cylinders, and

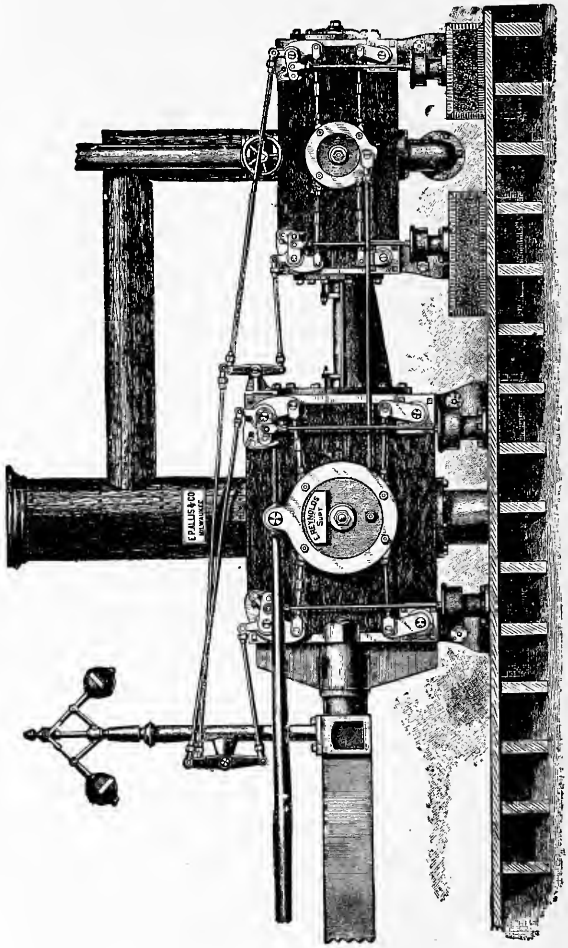
$$r = r_1^n;$$

where n is the number of cylinders adopted, r the total ratio, and r_1 the ratio for one cylinder. It will, however, for best effect, on the whole, be properly advisable to adopt a compromise between the various modified and conflicting values prescribed by the conditions that the work, the effective initial pressures, and the several products of range of temperature into exposed areas, shall be as nearly equal in all cylinders as possible. To meet the first condition we must have such a ratio in each cylinder as shall make the work in each equal to the total net power of the engine divided by the number of cylinders in series; to meet the second condition we must make the initial pressure in each such that the total range of pressure may be equal to a common range in each multiplied by the number of cylinders; while to make the stated products equal throughout the series we must have varying differences of pressure, the high-pressure cylinder having the maximum range, and the low-pressure cylinder the minimum range of pressure. The differences in this latter respect are, in engines using very high steam-pressures, quite considerable. Where the steam is dry, the speed of engine high, and the jacketing effective, this is a matter of less consequence than approximately uniform division of work and stresses on the crank-pins.

It is by the application of the principles which have been so fully described above that the steam engine for electric lighting purposes has been of late so greatly improved in respect to its economy of fuel and steam. The gain by compounding the smaller engines is so much greater than with the larger and originally more economical simple engines, that the disadvantage under which the high-speed engine has in some respects labored is to a considerable extent removed; and, among compound engines, all the common types are more closely competitive. All are approaching more and more a common ideal.

An often minor, yet real and sometimes important, advantage of multiple-cylinder engines is their greater freedom, with very high boiler-pressures especially, from liability to give trouble in lubrication. The steam-cylinders are the easier to lubricate as the range of pressure within them is less.

THE "TANDEM" ENGINE is perhaps the most common form of stationary compound engine. In this type, as shown in the accompanying illustration, the two cylinders are set in line, have a common piston-rod, and drive the same crank. The high-pressure cylinder is commonly placed behind the low-pressure, and the latter is directly attached to the frame of the engine. The exhaust of the smaller cylinder is carried in any convenient manner to the large engine; but the more direct and the larger the conduits employed the better. In some cases the two cylinders are set directly in contact. This plan involves a difficulty, usually, in packing the rod between them, but it has the advantage of great compactness.



"TANDEM"-COMPOUND ENGINE. (Scale $\frac{1}{24}$.)

THE COMPOUND CORLISS ENGINE was first introduced by other builders ; but no one was more successful in the economical working of the machine than was its great originator, the late George H. Corliss. The usual method of compounding this engine for stationary purposes is that known as the "tandem" system, in which the high-pressure cylinder is set behind the low-pressure, both pistons having a common rod and driving a common set of reciprocating parts and having valve-gearing actuated by the same eccentric and rod. The plan is simple, inexpensive, convenient, and compact, and is found to be very satisfactory in operation, the economy attained by it being about as high as that of any other arrangement yet devised. This method is illustrated by the illustration, which exhibits a form of the engine designed by Mr. Edwin Reynolds. It is readily seen that it would probably be impossible to find a better method of combining maximum efficiency with minimum cost of construction than this, or to make a more compact disposition of parts. It is necessarily of considerable length, but in other directions has no greater dimensions than the single engine of the simple type.

The performance of this type of engine has been most excellent. For example, the engines of the Nourse steam-mill, as constructed by Mr. Corliss, were found to demand no more than 1.62 pounds of good fuel per horse-power and per hour. The same engine as a simple engine, the high-pressure cylinder disconnected, if equal to the best of its class, under similar conditions of operation would probably not require less than two pounds ; which may be taken as about the limit of economical working for

that type of engine with a good condenser and dry steam.

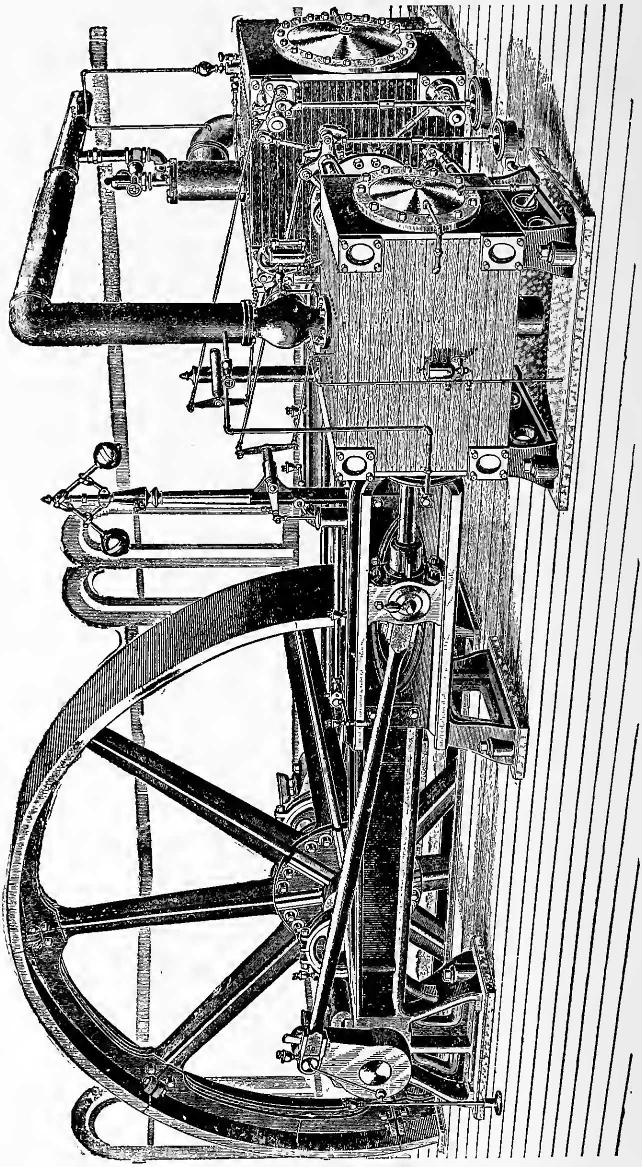
One disadvantage of this type of engine—the "tandem" —is the length of passage between the exhaust-port of the high-pressure and the induction-passage of the low-pressure cylinder when the former is taking steam in the backward stroke; but this is at least partly compensated by the very short passage obtainable for the opposite movement. The valve-gearing is commonly the same on both cylinders; but it is often so arranged that the governor operates on the one cylinder only, leaving the ratio of expansion of the other to be determined by the measure of expansion in the first.

Another not uncommon system of compounding this engine, especially for large powers, is oftener practised in Europe than in the United States; this is the coupling of two engines, side by side, as in common marine practice; while another method sometimes adopted is the adaptation of two independent engines of properly adjusted sizes to act, the one as the high-, the other as the low-pressure engine of a compound system. These engines are occasionally set at some distance apart, when the local conditions make that a more convenient disposition. The efficiencies of these several types of compound Corliss engines are substantially the same. They are all subject to about one-half the internal wastes of the simple engine of similar dimensions, to about double the external wastes of heat, and have a trifle more friction. On the whole they will ordinarily give an increased economy amounting to about twenty per cent of the heat and fuel consumption of the simple engine.

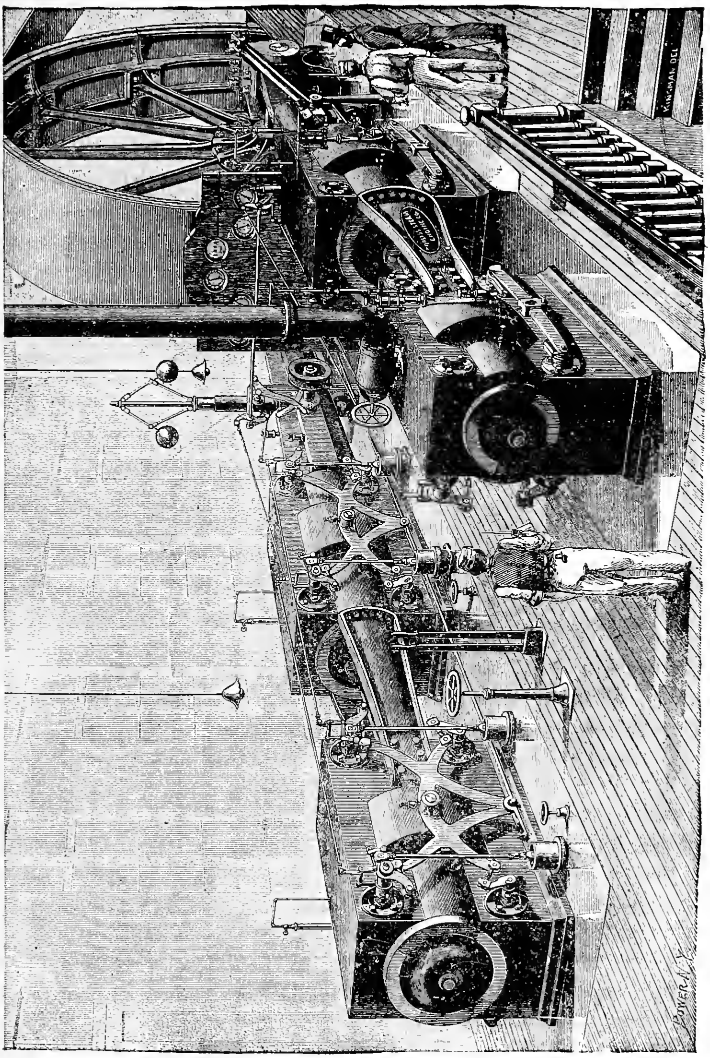
In some cases the arrangement of a pair of complete engines, of properly selected sizes, in such manner that either the exhaust of one may be used in the other or steam may be taken direct from the boiler to either is found advantageous. When less power is demanded, or when one is disabled, the available engine may then be used alone. Economy has been attained by this plan, even when the two engines are placed at considerable distances apart, the precaution being taken to carefully guard against loss of heat between them.

THE "CROSS-COMPOUND" type of Multiple-cylinder Engine is illustrated by the accompanying sketch of a pair designed by Mr. Reynolds and built by Allis & Co. for the Namquit Mills. The cranks are set at right angles, and the receiver is placed beneath the floor. This is a less common variety than the "tandem" form, but is still often adopted.

The general arrangement and disposition of the parts of a triple-expansion engine, as built by the Corliss Co., are seen in the next figure. Here the low-pressure cylinder is divided, one of its two elements being coupled with the high-pressure cylinder on the right, and the twin with the intermediate cylinder on the left. The cranks are set at 90°. These engines have cylinders 20, 34, 36, and 36 inches diameter, and 5 feet stroke of piston. All cylinders are completely steam-jacketed, heads included, and the steam is somewhat superheated. Jet-condensers are used. The capacity of the engine is 1,000 I. H. P. or more, and its "duty" is about 135,000,000 pounds; the fuel used, when of good quality, amounting, on test, to 1.44 pounds per horse-power per hour.



"CROSS-COMPOUND" ENGINE.



TRIPLE-EXPANSION CORLISS ENGINE.

"Compounding" simple engines is often a very economical and profitable plan. The method depends mainly upon the design of the engine to be so altered. The common forms of stationary beam-engine are commonly improved by what is called "McNaughting," placing a new high-pressure cylinder beside the old cylinder and connecting it to the beam either at the old air-pump center if condensing, or to the point at which an air-pump might have been attached, if the engine be non-condensing. The vertical marine engine may sometimes be altered into the compound form by placing the new cylinder above the old and the two pistons on a common rod.

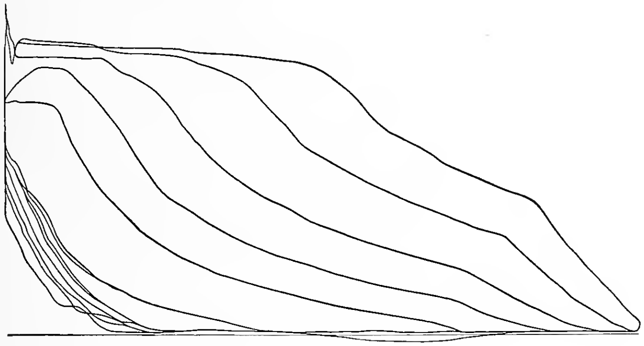
The straight-line engine.—Since the first introduction of this engine in 1880 there have frequently been made improvements in the details of construction and two important changes in steam-distribution.

In the use of constant lead and the specially devised valve-motion to accomplish it, it was discovered that a constant lead was not a desirable thing, and that changing to a variable lead (the reverse of that which obtains in locomotive practice) was very much of an improvement. By giving considerable lead to the valve when the engine is doing most work the machine is found to run more quietly and to do more work with the same steam-consumption; when running light a noticeable negative lead also secures quiet running as well as a more economical use of steam.

In the first case increased lead gives more compression and a freer exhaust, both of which are desirable; and in the case of a light load, when the compression (with a single valve) is too great in any event and the exhaust too

early, the changing of positive lead to negative reduces the compression and prolongs the exhaust.

Further than this—to utilize a principle made prominent (if not discovered) by Willans in his extended experiments, that after a certain point of cut-off is reached it is more economical to reduce the pressure than to increase the number of expansions, as would be the case if the cut-off was made shorter ; and in correspondence with experiments made by Mr. E. J. Armstrong in conjunction with Mr. Sweet—further changes have shown that it is possible to accomplish the result with the single valve. The card below, taken with a variable load, shows to what extent this has been carried.

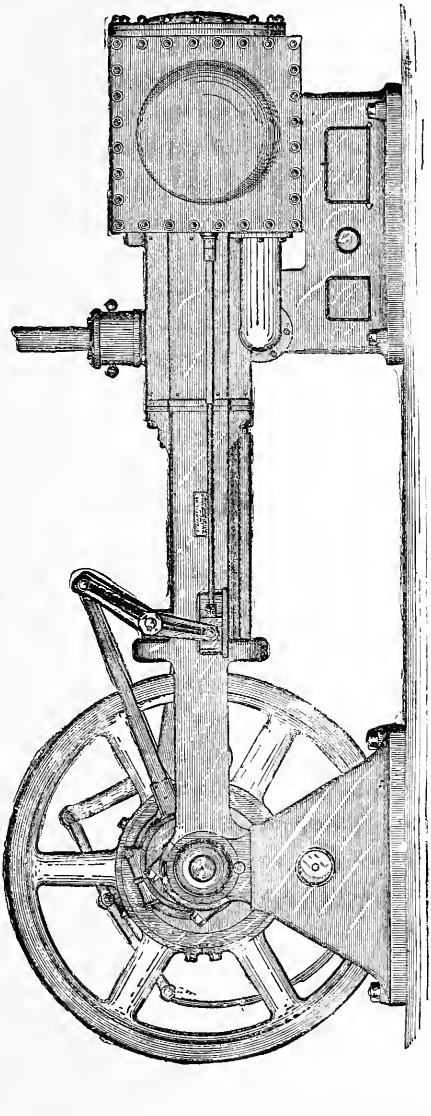


STRAIGHT-LINE DIAGRAM.

Another change recently made has been the introduction of a separate exhaust-valve, making the steam-distribution nearly the same as in the Porter-Allen engine except that the cut-off is carried through a wider range, varying from three-quarter stroke to zero, and, too, the lead is

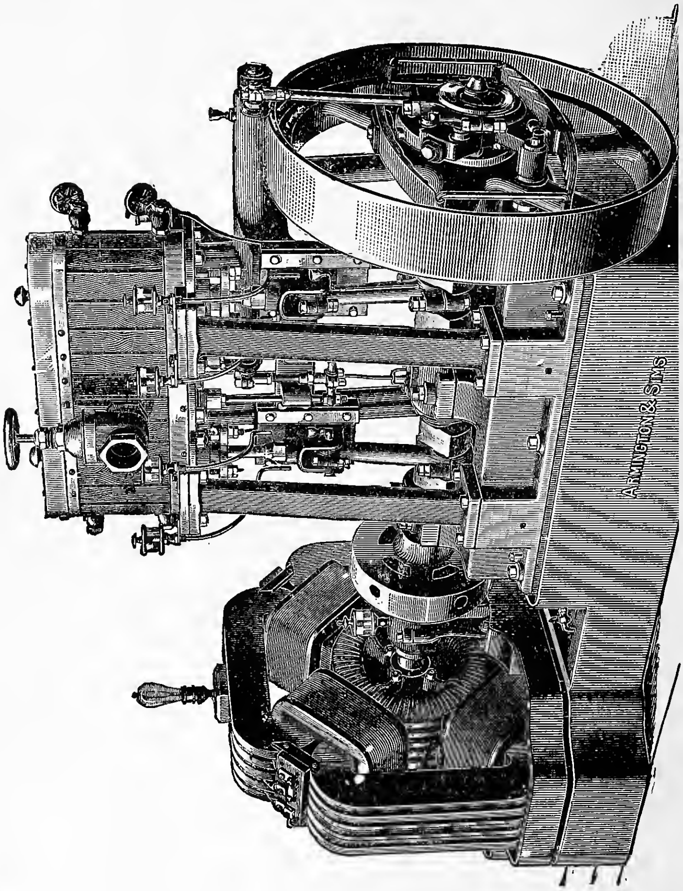
varied from positive to negative as the cut-off is reduced, insuring still running at both light and heavy loads.

The Compound Form of the Sweet engine is one of the best of illustrations of the compactness which may be given the "tandem" type of the machine. The engine is built, as to its high-pressure cylinder and working parts, precisely like the standard type of the simple engine of the same design. It has exactly the same characteristic form of frame and methods of connection and of steam-distribution and governor. Directly behind the high-pressure cylinder, however, is placed the larger, low-pressure, cylinder, the whole forming practically one structure. The whole machine can be taken apart and reassembled without disturbing the cylinders or the frame. Both pistons, which are mounted on one rod, can be removed and replaced, the intermediate head coming away with its stuffing-box through the larger cylinder. The packing of the rod between the two cylinders is a metallic sleeve, solid and free from liability to produce trouble or to require readjustment, once in place and properly fitted. It is free from liability to wear or to bear upon the rod in such a manner as to produce undue friction and heating, while it is loose enough to work smoothly, and yet tight enough to prevent leakage of steam past its shell. The valve of the low-pressure cylinder is worked by an independent, fixed, eccentric, and the expansion is adjusted by the action of the governor, affecting the point of cut-off on the high-pressure cylinder, precisely as in the simple engine. Where the load is fairly steady this arrangement is perfectly satisfactory. The in-



THE SWEET COMPOUND STRAIGHT-LINE ENGINE.

ventor has also planned a triple-expansion vertical engine of equal simplicity.

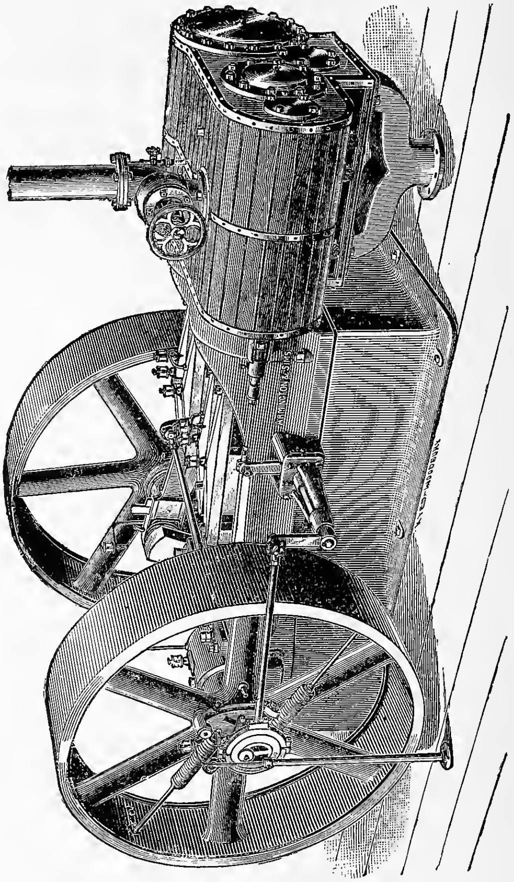


DIRECT-CONNECTED DOUBLE ENGINE FOR DYNAMOS.

THE ARMINGTON & SIMS ENGINE was among the first of the "single-valve automatic" engines to find a place in

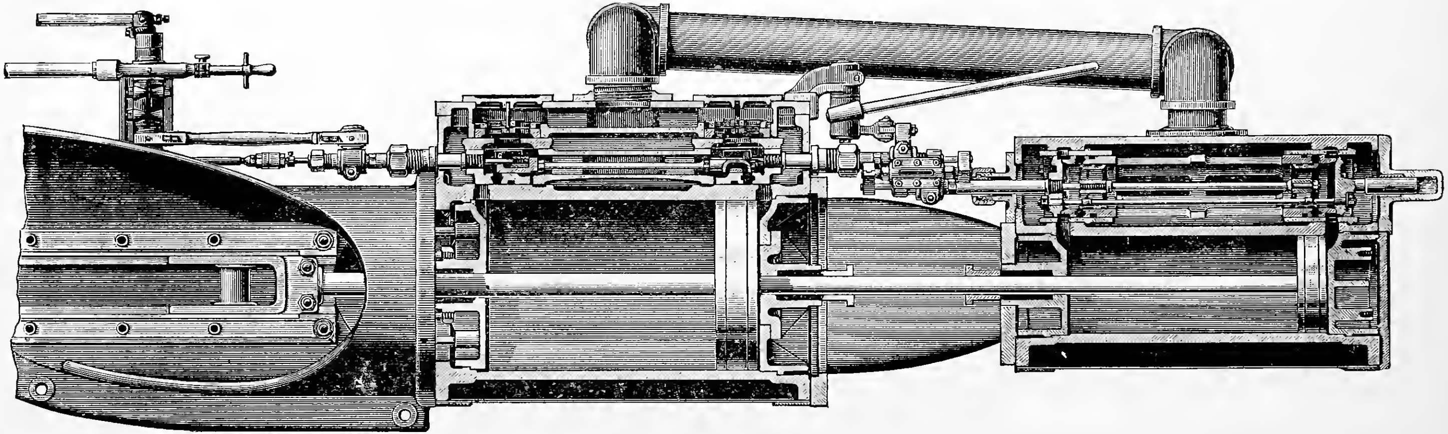
electric lighting, and it was also one of the earliest to be built as a compound engine. An experimental engine was built about 1880 ; but the engine was not constructed as a multiple-cylinder engine regularly and as a standard type until some years later. The form given this engine is seen in the accompanying illustration, which represents the machine as constructed to give 100 horse-power at high speed. The regulation and the general construction of each of the two elements of the compound engine are similar to those already described in the simple engine. The two cranks are placed opposite, and this gives that perfection of balance which cannot be secured by any other device. It is also the best method of obtaining transfer of steam from the one engine to the other with minimum loss of pressure. The attainment of a speed of 800 revolutions a minute is possible. Both cylinders are steam-jacketed. Such engines are usually made up to about 200 horse-power. In the type here shown, the cranks being opposite, the engine balanced, it can safely be run at a high speed ; the peculiar form of the valve provides for quick admission of steam, and the large wearing-surfaces insure it more or less fully against leakage ; the pistons and stuffing-boxes used are more easily got at than ordinarily with engines of the "tandem" type.

One of the earliest to adopt compounding as a system of standard construction was Mr. Thompson in the "Buckeye" engine in 1879. This engine, tested by Mr. Barrus, gave an economy measured by 19 pounds of dry steam per I. H. P. per hour. The gearing lends itself readily to any type of construction, and the engines are built in three



ARMINGTON & SIMS COMPOUND ENGINE.

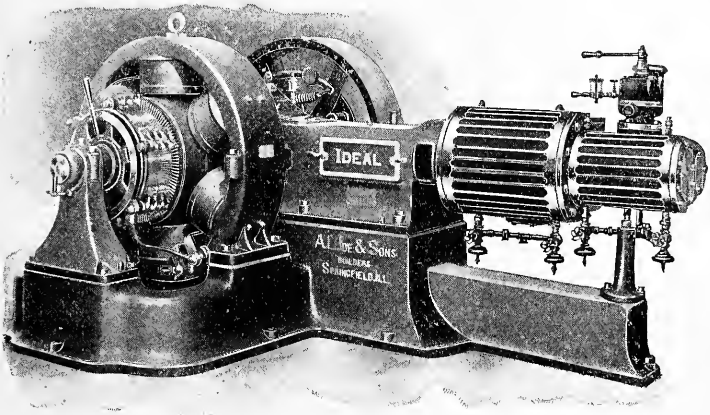
[*To face page* 211.]



TANGYE BED TANDEM-COMPOUND ENGINE.—SECTIONAL PLAN OF CYLINDERS AND VALVE GEAR.

classes, ranging from what are now considered low to tolerably high speeds. The figure shows in section the arrangement of cylinders and valves and connections in the "tandem-compound" engine, a form commonly employed because of its simplicity and cheapness, compactness and freedom from liability to derangement. In many of these engines piston-valves are used when steam-pressures are very high.

In the drawing are well shown the small clearance characterizing this form of cylinder and valve. In this, as in the previously described forms of the same engine, constant travel of the valves, giving freedom from leakage, and a wide range of expansion if needed, can be secured within any reasonable limits.

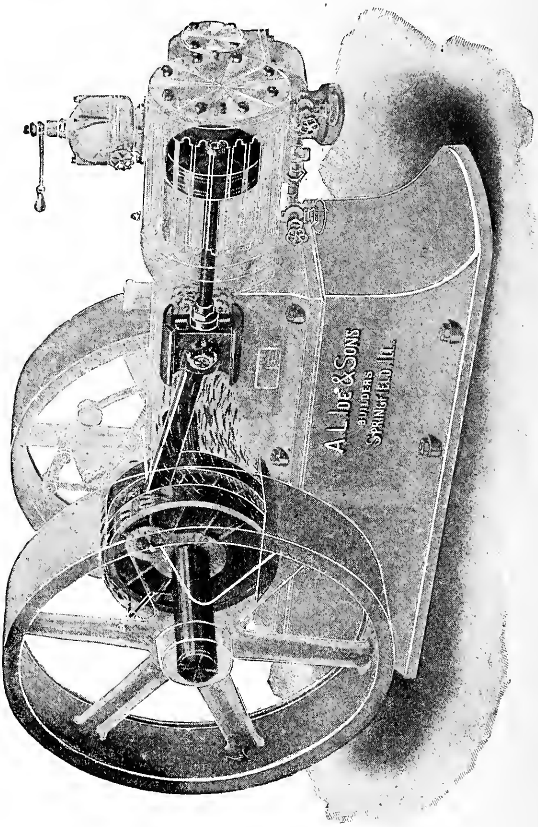


TANDEM-COMPOUND ENGINE AND DYNAMO.

The "Ideal" is a more recent development of the Ide engine, and involves particularly the self-oiling system already described in the case of the Worthington engine.

The problem which designers must here solve is that of combining effective lubrication with neatness.

They have here not only secured copious lubrication, flushing the bearings in oil, but have attained a degree of



"SEMI-SECTION," HIGH-SPEED ENGINE.

cleanliness and freedom from throwing oil over the parts of the engine or floor that cannot be equaled by the older type. With a "bath" system of lubrication—bearings

flushed in oil—we overcome the principal objections that have been urged against the life of high-speed engines in addition to the excellent running balance attained in the latest product, resulting in cleanliness and quiet running, and the ability to run the engines for an indefinite time without stopping.[1]

The following are the principal dimensions of this engine with 400 K. W. General Electric generator attached, running non-condensing.

COMPOUND DIRECT-CONNECTED ENGINE.

Cylinders 19″ and 32″ by 42″.

Speed 100 revs.

Weight of fly-wheel 43,000 lbs.

Diam. of crank-shaft 18″, steel forging.

Crank-pin 9″ × 9″.

Cross-head pin 6″ × 7″.

Connecting-rod 5½″ cranks.

Cross-head shoes, phosphor-bronze, 12″ × 24″.

Piston-rods 3½″ and 4½″.

The high-pressure valve is actuated by an automatic governor, the same type as in the Ideal engine.

The high-pressure valve is the Ide adjustable piston-valve.

The low-pressure valve is actuated by independent adjustable eccentric.

The low-pressure valves are of the Porter-Allen type, provided with pressure-plates.

1. See Friction and Lost Work in Machinery and Millwork.- R. H. Thurston; N. Y., J. Wiley & Sons.

Each cylinder is provided with $2\frac{1}{2}''$ automatic relief-valves.

Weight of engine 145,000 lbs.

A good idea of the disposition of parts in the tandem-compound engine is obtained from the sketch.

The next figure represents an automatic compound engine designed by Mr. F. H. Ball especially for use in driving dynamo-electric machinery.

The illustration represents an engine using steam at 125 pounds pressure and of 250 horse-power.

It was thought best to build these engines in the form of a double engine rather than the "tandem" type of compound, because it was believed that higher rotative speed could be successfully used where the work was distributed over two sets of crank-pins and journals of smaller sizes, rather than with the use of a single set of bearings of larger size, as in the case of a tandem engine developing the combined power of the double compound.

The cylinder dimensions selected after working up a large number of provisional diagrams were as follows:

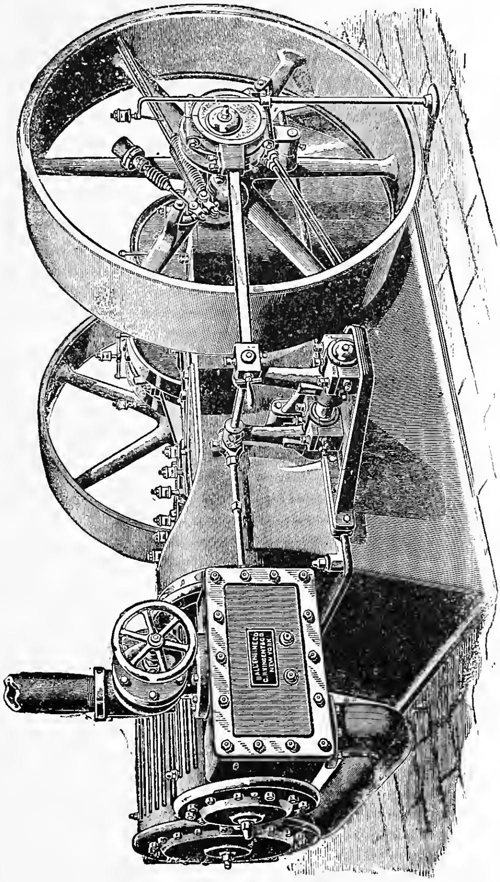
High-pressure cylinder: diameter $13''$; stroke $16''$. Low-pressure cylinder: diameter $25''$; stroke $16''$.

The maximum power attained on trial was 325 I. H. P.

The next figure illustrates the same make of engine compounded in the more usual way, a "tandem"-compound high-speed engine for electric lighting or other purposes, which is found to be one of the best combinations of efficiency with simplicity and small cost.

Nearly all makers now use this method of compounding for all cases except where, as in marine engines, a double engine with cranks at right angles is considered desirable on

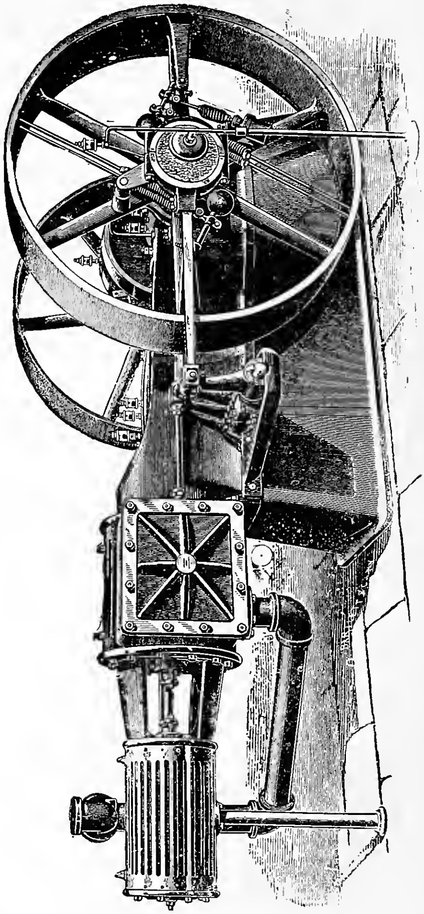
other grounds. They are nearly as simple in form, as cheap of construction, and as inexpensive in repairs as the simple engine.



BALL "CROSS"-COMPOUND ENGINE.

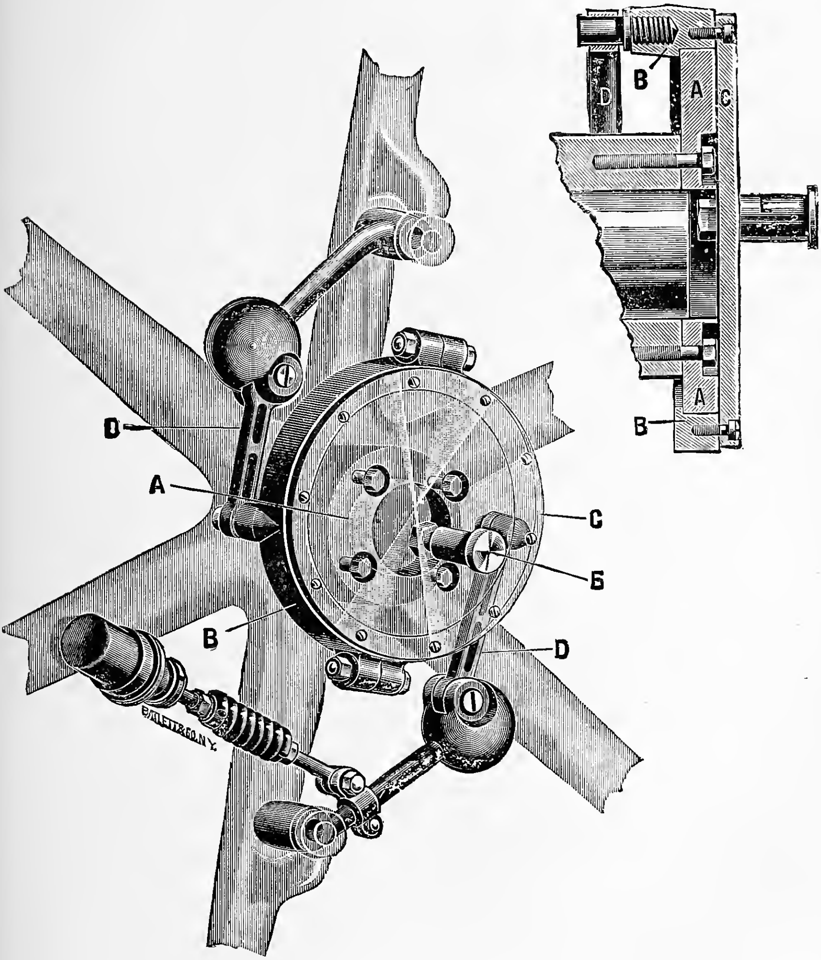
The methods of construction and of setting up a governor are well illustrated in the case of the Ball governor, as

seen in the figure. The eccentric *A* is a small disk solidly bolted on the end of the wheel-hub, and as small and light



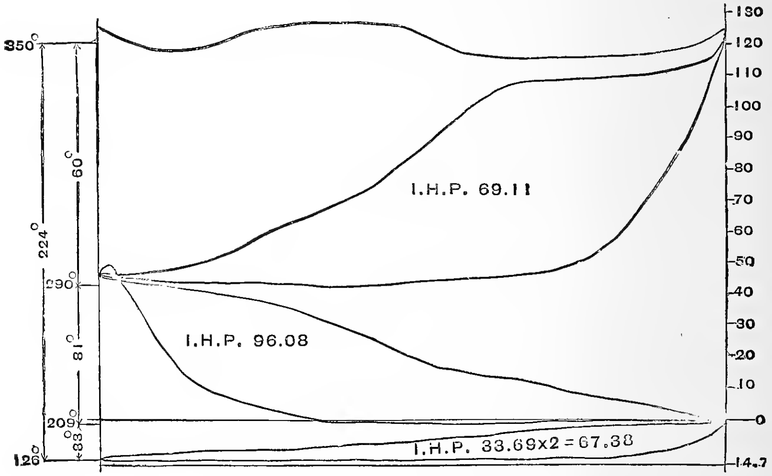
TANDEM-COMPOUND HIGH-SPEED ENGINE.

as is consistent with satisfactory operation. The strap *B* is, as usual, in halves, but it is held in place by a thin disk,



Ball's Governor.

C, on one side and the not uncommon flange on the other. Links, DL, connect the strap and the weight sof the governor ; while a pin, E, set in the cover-plate, actuates the valve as usual. The center of the eccentric is so located that its motion relatively to the wheel, as produced by the governor, causes E to describe an arc about the eccentric-centre giving the desired variation of cut-off with nearly constant lead, except at very high ratios of expansion, where the lead is rapidly taken off. When the engine is subject to irregular changes of speed due to inertia or gravity



TRIPLE-EXPANSION DIAGRAM.

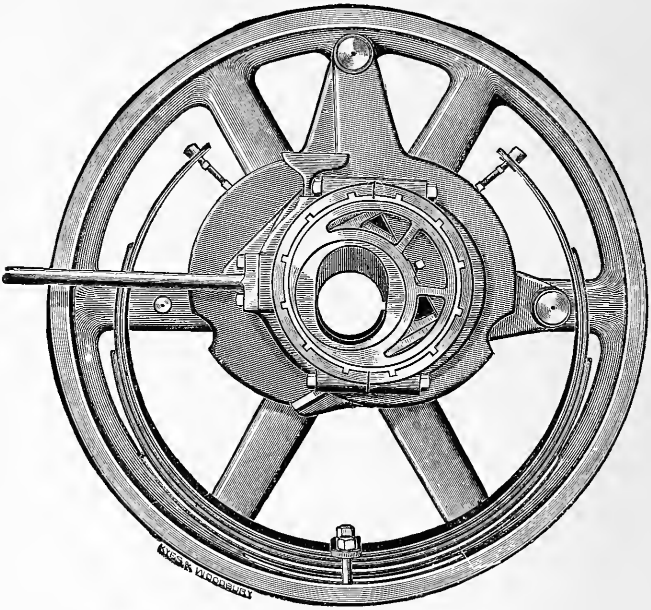
in the governor, the dash-pot should be introduced as in the illustration. The method of assemblage is well shown by the peculiar method of engraving the latter figure, a method introduced by Westinghouse.

The diagram here reproduced illustrates a good adjust-

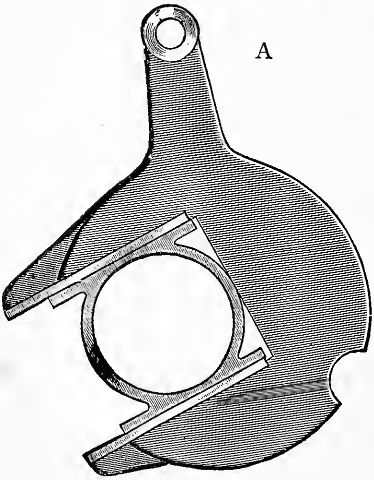
ment of such a valve system, and was taken from an engine, designed by Mr. Ball, having four cylinders and of the triple-expansion type, placed in their proper order of relation and reduced to a common scale. The ranges of temperatures in the several cylinders are also exhibited at the left. In each cylinder the compression is adjusted, as seen, to fill the clearance-spaces, and no appreciable "drop" takes place. The two low-pressure cylinders develop nearly the same amount of power as the high-pressure, and the latter about 0.7 as much as the intermediate cylinder. The upper line shown exhibits the steam-chest pressures and the loss due to the throttling action of a long steam-pipe.

The shaft-governor is a "safety-governor," and if any part breaks or becomes deranged in any way the result is to stop the engine. The use of the dash-pot was probably resorted to at an early date for the purpose above described.

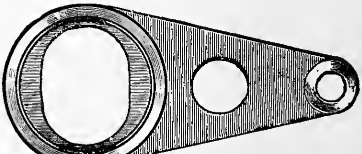
Messrs. McIntosh & Seymour have also devised an interesting modification of the Hartnell type of governor. This is shown in the figure, page 220. It consists of a pair of pivoted weights, one of which is shown separately at *A*, having inclined jaws, in which slide two blocks. These blocks turn freely on a boss upon the pendulum, shown on *B*, to which the eccentric is attached, and which is free to swing across the shaft. The pendulum is pivoted in such a way that while the cut-off changes from five-eighths to zero the steam-lead does not vary. The inclination of the jaws in the weights is such that, through the action of friction, their position is not influenced by the action of the valve



A

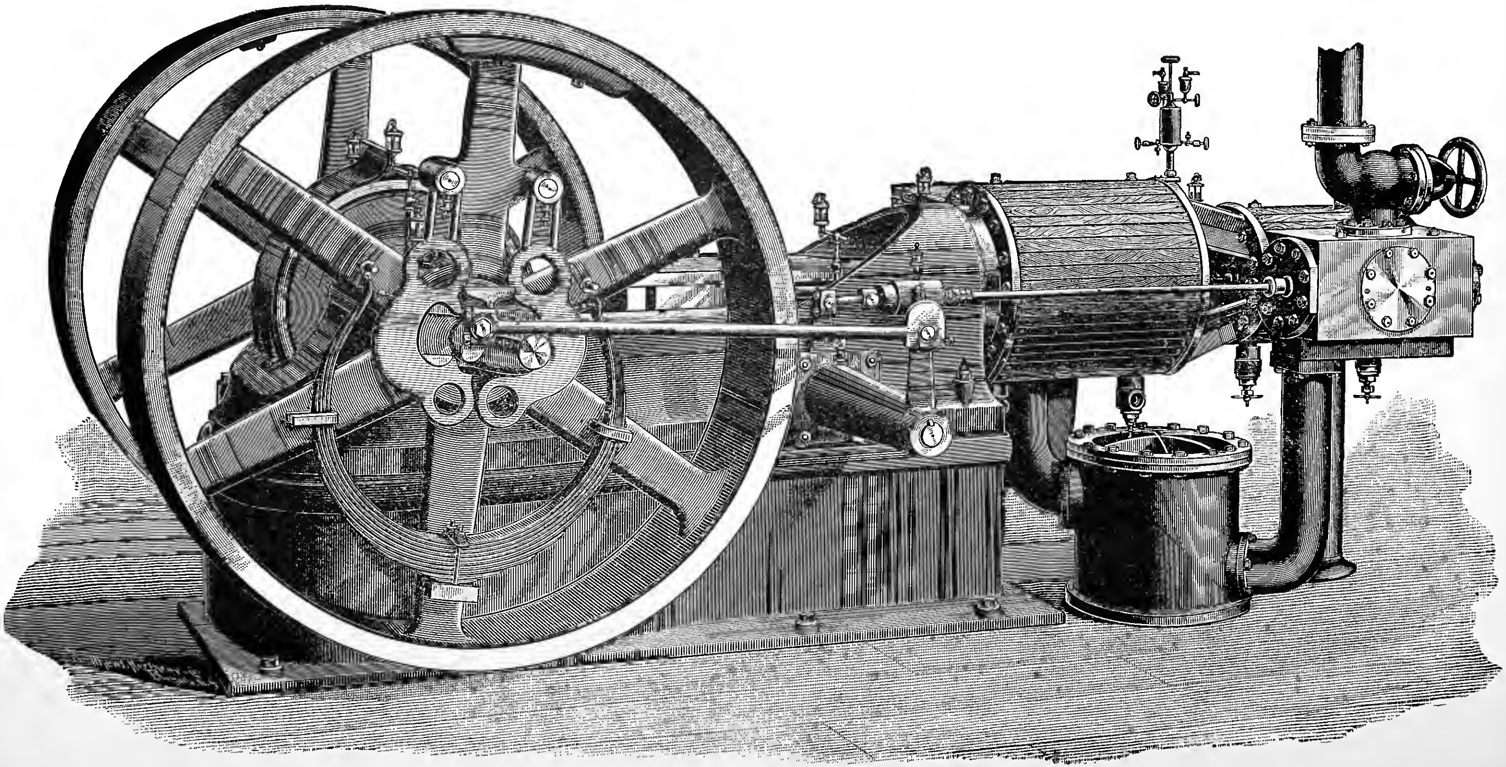


B



McIntosh & Seymour Governor and Details.

[*To face page 221.*]



THE McINTOSH AND SEYMOUR COMPOUND ENGINE.

and rod, and yet they are always in statical equilibrium and have no tendency to race. The spring bears upon the weights through the hardened-steel pins, one end of each pin resting in a hardened cup on the end of the spring and the other in a slot in the weight. These slots are made deep, so that the pin bears upon the center of gravity of the weight, and the pressure of the spring directly opposes the centrifugal force.

The arrangement of the governor on the engine is seen in the accompanying full-page engraving of the tandem compound of this make.

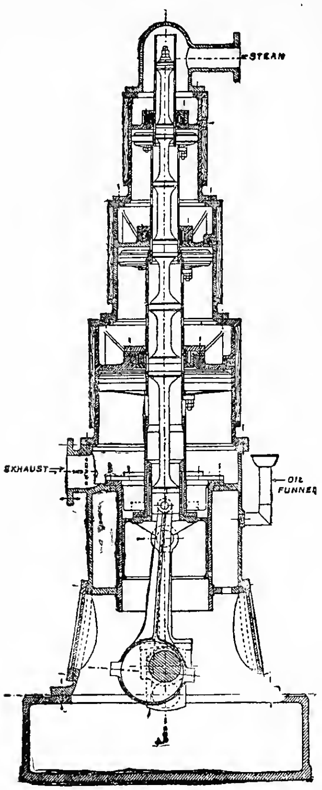
The engine itself illustrates a now standard construction. The high-pressure cylinder and the receiver are jacketed. The two valves are placed on opposite sides of the engine to secure direct connection and accessibility. The receiver takes jacket-steam from the high-pressure cylinder jacket and returns all water of condensation to the boiler. The governor system actuates the high-pressure valve, the low-pressure eccentric being fixed. The general proportions of parts can be judged from the illustration.

An ingenious modification of the enclosed single-acting compound type of engine, the "central-valve engine" of Mr. Willans—which is also interesting as having been the subject of exceptionally complete scientific investigation —is seen in this figure.[1] It was studied as a simple, a compound, and a triple-expansion engine, being easily adapted to either system.

As here shown, its three cylinders are placed in series

1. The discussion of this paper is remarkably interesting. Trans. Brit. Inst. C. E., March, 1888; 1887–18.9; No. 23c6, Vol. XCIII.

and "tandem." The valves are on one rod, driven by a single eccentric on the crank-pin ; the rod being in the axis of the engine and the valves within the hollow piston-rod. Cut-off is effected by the passage of the ports into metallic rings in the ends of the cylinders, and is adjustable by hand or by the governor. Compression is effected in the separate cushion-chamber.[1]



WILLANS' ENGINE. (Scale $\frac{1}{16}$.)

These engines are usually grouped in pairs, with cranks at right angles.

As the valve-faces move with the pistons, the valve-motion must here be taken from the pins to secure the desired movement relatively to the pistons. The work on the main journals and pins is substantially all on the upper "brass" of the latter and the lower of the former, and the crank-pin working-side is never expected to leave the pin. The eccentric-rod, like the connecting-rod, is always in compression, and the main bearings also are always under constant downward thrust. Lubrication is secured, by the

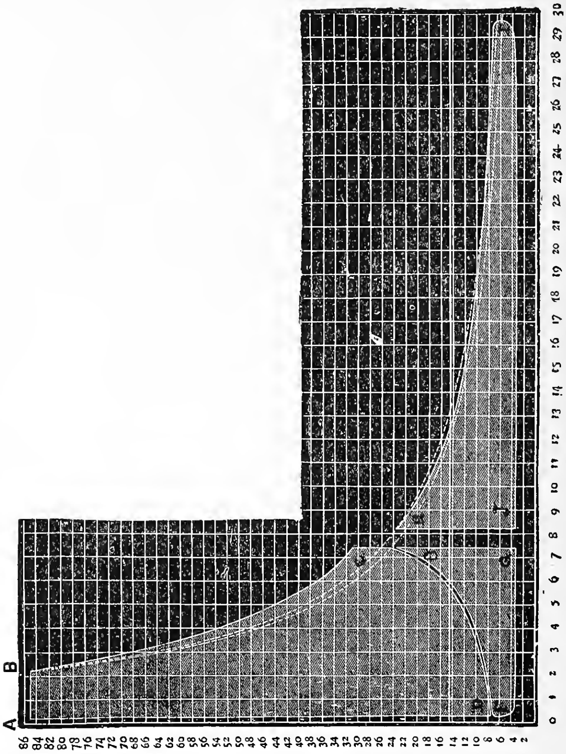
1. Trans. Brit. Inst. C. E., Vol. LXXXI. p. 166.

Westinghouse method, by the dipping of the crank into a pool of oil and water in the crank-case. The guide-pistons are arranged to produce the needed cushion by compression of the air in the compression-chambers, and this is adjustable as may prove to be advisable. The governor is of the now familiar Hartnell type.

MULTIPLE-CYLINDER DIAGRAMS take forms as follow: In this illustration from Mr. Porter's report [1] the natural form of the expansion-line in the single cylinder having the capacity here observed in the low-pressure engine, would be that shown by one or other of the two dotted lines, accordingly as the expansion approaches more or less closely the hyperbolic form. The initial volume is *AB* and the pressure as shown on the vertical scale, while the gradual loss of pressure with increase of volume is shown by the two scales as the line progresses toward the right to its terminal point at *I*. The deviation from the dotted line of the actual expansion-line between *B* and *C* illustrates the gain of weight and pressure due to the progressing re-evaporation of steam originally condensed in the cylinder at the opening of the steam-valve and to the admission of the fluid into the colder cylinder. Here expansion occurs from the initial pressure and volume at *B* down to the terminal point *C* in the high-pressure, and from *C* or *H* to *I* in the low-pressure, cylinder. The indicator-diagrams actually obtained are *ABCD* and *EFG*, the latter being the equivalent in the low-pressure cylinder of the card *HIJ*, which would have been produced had the high-pressure cylinder been given sufficient length to permit the

1. Manual of the Steam Engine, R. H. Thurston, Vol. II. p. 59.

completion of the expansion in that cylinder. The variation of the full line, representing the real diagram, from the ideal dotted expansion-line is indicative of the fluctuations

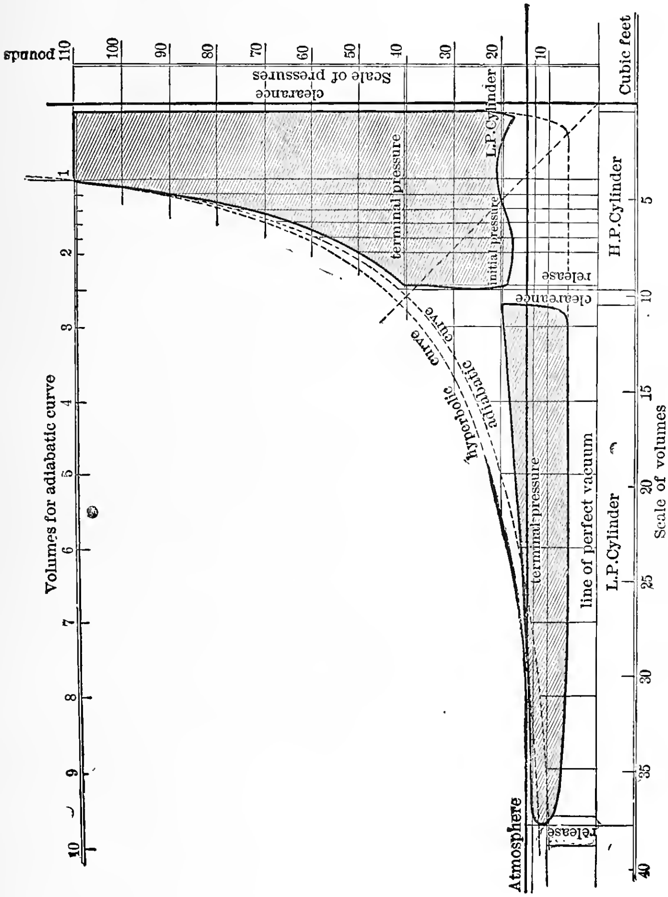


COMPOUND-ENGINE DIAGRAMS.

of pressure produced by the condensation and re-evaporations taking place as expansion progresses in the metallic chamber serving as working-cylinder.

The succeeding figure illustrates the visible differences between the diagrams actually taken from the two cylinders

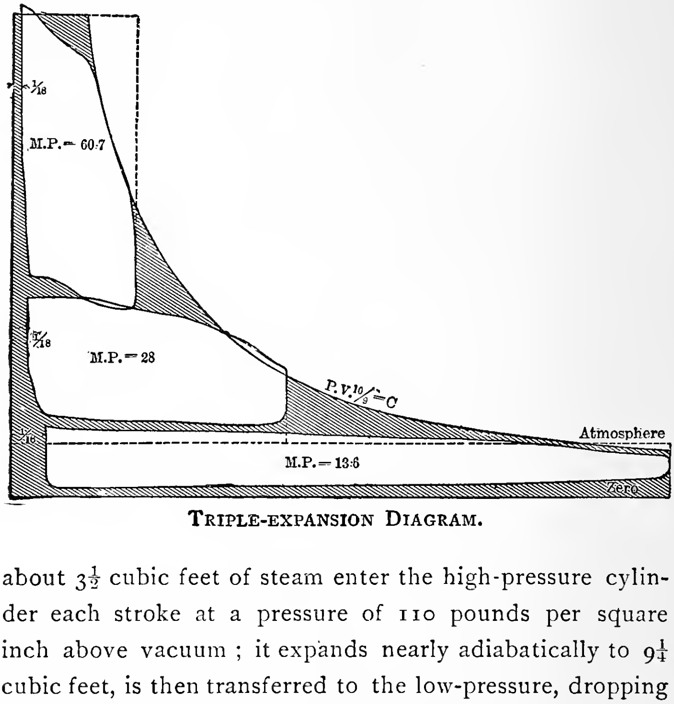
of a compound engine—in this case a "Reynolds-Corliss" —and the ideal combined card.



ACTUAL AND IDEAL DIAGRAMS. COMPOUND ENGINE.

This shows the method of reducing the actual indicator-diagrams to the combined form, and the variations from

the ideal expansion-line due to imperfections of the engine as a work of human art. Pressures are measured in pounds on the square inch and volumes in cubic feet, actual capacities of cylinder being given. As shown on the diagram,



TRIPLE-EXPANSION DIAGRAM.

about $3\frac{1}{2}$ cubic feet of steam enter the high-pressure cylinder each stroke at a pressure of 110 pounds per square inch above vacuum; it expands nearly adiabatically to $9\frac{1}{4}$ cubic feet, is then transferred to the low-pressure, dropping from the terminal pressure, 40 pounds in the high-pressure cylinder, to 20 in the low-pressure, and then expanding in the latter down to about 12 pounds, it passes into the condenser, the back-pressure thus becoming not far from an average of 6 pounds. The two indicator-diagrams are shown by the "hatched" spaces; the ideal diagram en-

closes both, its outline being the dotted lines. The very considerable space measuring the difference of the two areas is a gauge of the imperfection of the cycle. The departure of the actual line from the two ideal expansion, curves, and the fact that the former lies within both the latter, indicate that the jacket does not supply heat enough to compensate the condensation of the expanding fluid, far less enough to retain its temperature constant or to continuously superheat it.

The discordant fluctuations of similar lines in the two indicator-diagrams exhibit the effect of non-synchronous motion of the two cylinders.

The last illustration exhibits the proportions of diagrams taken from a triple-expansion engine drawn to common volume and pressure scales and placed under the Mariotte line. The engine has cylinders having the ratios 1 : 2.25 : 2.42, and the total ratio of expansion is 8, the cut-off in the several cylinders being set at 1.47, 1.3, 1.3. An advantage of this type of receiver-engine, with its cranks making equal angles, is that the drop in pressure may be made unimportant.

In the receiver-engine the less the drop of pressure at the end of the stroke, at the passage of the exhaust-steam into the receiver, the less the waste.

The action of the steam and its variations of pressure are, throughout the cycle, precisely similar to that in a simple engine. Large steam-ports and a good expansion-gear bring the steam-line close up to that of boiler-pressure ; a well-jacketed cylinder allows the expansion-line to follow closely that laid down for the ideal engine ; short and free

ports between the two cylinders give an exhaust from the high-pressure and a supply to the low-pressure cylinder which are nearly coincident; and the two cards would, if reduced to a single diagram, exhibit a very close approximation to that which would have been constructed as the ideal diagram of this class of engine. When these points are not well attended to, variations of twenty and even thirty or forty per cent may be observed between the computed power, as based on the designer's indicator-cards and the actual work of the engines under their ordinary conditions of operation.[1]

It has long been known that there may be determined a certain definite ratio of expansion in the high-pressure cylinder of a multiple-expansion engine, such that, at that ratio, the mean pressure on its piston is a maximum.[2]

Thus, assuming hyperbolic expansion, and taking

v_1 = volume of the h.-p. cylinder;
v_2 = " " " next " ;
$\frac{v_1}{r_1}$ = cut-off in the h.-p. " ;
r_1 = ratio of expansion h.-p. cylinder;
p_1 = initial pressure in " " ;
$p_2 = p_b$ = pressure at end of its stroke;
$1 \div r_2$ = cut-off in the l.-p. cylinder—

$$= p_2\ p_1 \frac{v_1 \div r_1}{v_2 \div r_2} = \frac{p}{r_1 r_2};$$

1. For a full and clear treatment of this subject in its minor details see D. K. Clark's Manual, p. 849 *et seq.*, or his Treatise on the Steam-engine, 1889–90.
2. Trans. Inst. Nav. Architects of G. B., Vol. XIX. p. 205.

while the work done per stroke is

$$U = p_1 v_1 \frac{1 + \log_e r_1}{r_1} - p_2 v_1 = p_1 v_1 \left(\frac{1 + \log_e r_1}{r_1} - \frac{1}{r_1 r_2} \right),$$

which is a maximum when, taking r_1 as variable,

$$\log_e r = \frac{1}{r_2}.$$

When $r_2 = 1$, as in the ordinary engine, we have

$$r_1 = e = 2.718.$$

Thus, for example, with cylinders having volumes as $4:1$, $r_2 = 2$; steam at 80 lbs. pressure, $r = 1.65$ and $p_m = 45.4$ lbs. per square inch.

This value is somewhat modified by the presence of the intermediate passages between the cylinders, a drop occurring in the pressure at the instant of opening the exhaust from the small cylinder; but this drop is less as those passages are larger; and if forming an intermediate reservoir, as is sometimes the case where "reheating" between the cylinders is practised, this loss and the corresponding reduction in the mean pressure obtained, in work done and in the actual total ratio of expansion, is sometimes quite unimportant compared with the gain by that process. A common value for the reduction of total expansion is not far from 20 per cent, rising to one-third with small reservoirs and falling to a lower figure with larger spaces. The loss of work may usually be neglected.

The receiver type of engine with equidistant cranks and intermediate reservoirs is less seriously affected by intermediate spaces. The reduction of pressure and the loss of

total expansion is but about 10 per cent where the receiver-space is equal to the volume of the smaller cylinder, and falls to less than 5, in usual cases, when the receiver is large.

THE PROPORTIONS OF PARTS of engines of the "high-speed" class have been made a subject of special study by Professor J. H. Barr. The mathematical principles of applied mechanics and of the strength of material as developed by writers on the subject are necessarily accepted by the designer with some reservation, since he must design his engine for safety, meeting the accidental stresses due all forms of contingency to be fairly anticipated in its operation with ordinarily good management under average working conditions. Original computed proportions are thus, in all engineering, subject to continual readjustment in the light of experience. The proportions representing good average practice are given in the table.[1]

It occurred to Mr. Barr that it might be possible to derive formulas which would express, more or less closely, the conclusions arrived at as the result of experience in engine-construction. These formulas are empirical in the sense that they are adjusted to agree with observations; but they should be rational in form.

There is a striking general agreement among builders of standard engines of each type as to the proportions of many parts, making due allowance for differences of conditions, and practice has settled down to somewhat definite lines.

The data sought were entered on a blank thus:

1. Trans. A. S. M. E., Dec. 1895, Vol. XVII. No. DCLXXII.

FORM FOR ENGINE DATA.

Schools of Mechanical Engineering and of the Mechanic Arts.
R. H. THURSTON, Director.

SIBLEY COLLEGE CORNELL UNIVERSITY,
Machine Design.
JOHN H. BARR.

Data on..*Steam-engines*. 189..

1	Diameter of cylinder............							
2	Length of.stroke................							
4	Revolutions per minute..........							
6	Rated horse-power.............							
18	Face of piston..................							
19	Diameter of piston-rod..........							
20	Material " " "							
22	Mid-section of connecting-rod...							
27	Diameter of crank pin							
28	Length " " "							
30	Area of cross-head shoes........							
32	Diameter of main journal.'......							
33	Length " " "							
35	Length of shaft, c. to c. bearings.							
36	Material of shaft..............							
39	Diameter of fly-wheel...........							
40	Face of fly-wheel...............							
41	Total weight of fly-wheel........							
42	Weight of rim of fly-wheel							
52	Weight of complete engine......							

The data obtained in this way were very complete, covering 75 engines by 12 builders, the sizes of engines ranging from 25 to 225 rated horse-power.

The following notation is used :

D = diameter of piston ; A = area of piston ; L = length of stroke ; S = steam-pressure, taken at 100 pounds per square inch above exhaust as a standard pressure ; H. P. = rated horse-power ; N = revolutions per minute ; C = a constant. All dimensions in inches, unless stated to the contrary.

The general method employed in deriving the various expressions may be illustrated by reference to that used for the diameter of the crank-shaft at the main bearings.

Crank-shaft.—d = diameter of shaft. The formula for the diameter of a shaft which is subjected to torsion is $d = C\sqrt[3]{\text{H. P.} \div N}$, if the moment of torsion is constant.

The constants found as above give

$$d = 7.56\sqrt[3]{\text{H. P.} \div N} \text{ for the mean,}$$
$$= 8.76\sqrt[3]{\text{H. P.} \div N} \text{ " " maximum,}$$
$$= 5.98\sqrt[3]{\text{H. P.} \div N} \text{ " " minimum.}$$

For example: If an engine develops 100 horse-power at 250 revolutions per minute, the first of these formulas gives

$$d = 7.56\sqrt[3]{100 \div 250} = 7.56\sqrt[3]{.4} = 7.56 \times .737 = 5.57$$

inches, or say $5\frac{1}{2}$ inches.

The formulas give the range of sizes from $4\frac{1}{2}$ inches to $6\frac{1}{2}$ inches.

Piston-rod.—The expression is based upon the Euler formula for a long strut: $P = cEI \div l^2$, in which P is the load, E the modulus of elasticity, I the moment of inertia of section, and l the length of strut. P is proportional to the square of the piston diameter (D^2) for any given pressure. $I = \frac{1}{64}\pi d^4$ for a circular section; l is taken equal to the length of stroke, L. Collecting and solving,

$$d = C\sqrt[4]{D^2L^2} = C\sqrt{DL}.$$

The equation of the mean gives .145 as the value of C, while the extreme values are .119 and .177, the minimum and maximum values, respectively.

Connecting-rods are first treated as long struts, then the allowance for flexure-stresses due to inertia is examined.

For resistance to buckling in the plane of motion the connecting-rod is treated as pin-connected or round-ended; for flexure in a plane at right angles to this the strut is square-ended. Hence (neglecting inertia) the thickness or breadth (b) of a rod of rectangular mid-section should be one-half the height (h). The formula for breadth is $b = C\sqrt{DL'}$, in which L' is the length of the rod.

The data examined give .0545 as the mean value of C, with .0433 and .0693 as the minimum and maximum values.

The excess of h over $2b$ may be a provision for stresses due to inertia. To show this allowance points were plotted having corresponding values of b and h for the co-ordinates. This curve shows that h is from 2.18 to 4 times b, the mean value being $2.73b$.

Main journals.—The length of journal to prevent heating is $l = C\frac{\text{H. P}}{L}$, but the data are insufficient to clearly locate the mean.

For projected area of each bearing $dl = C'SA = CA$, C ranging from .367 to .739, the mean value being .489.

If p is the pressure per square inch of projected area,

$$2pdl = SA\ ;\ \text{hence}\ \frac{2pdl}{S} \times \frac{dl}{C}\ \text{or}\ p = \frac{S}{2C}.$$

With steam-pressure of 100 pounds this gives about 100 pounds as the pressure per square inch of projected area, using the mean value of C, while 140 and 70 are the extreme values of p.

Crank-pin.—The length of crank-pin is $l = C\frac{\text{H. P.}}{L}$. The equations derived are respectively

$$l = .333\left(\frac{\text{H. P.}}{L}\right) + 2.2 \text{ inches, mean ;}$$

$$l = .192\left(\frac{\text{H. P.}}{L}\right) + .88, \text{ minimum ;}$$

$$l = .417\left(\frac{\text{H. P.}}{L}\right) + 3.92, \text{ maximum.}$$

The data are insufficient.

The projected areas of the crank-pins were

$$dl = .22A, \text{ mean ;}$$
$$= .07A, \text{ minimum ;}$$
$$= .44A, \text{ maximum.}$$

These values give (for steam 100 pounds per square inch) 450, 1,400, and 225, mean, maximum, and minimum, respectively.

Face of piston.—A wide divergence was noted in the ratio of diameter to face of piston. The following formulas were obtained:

$$\text{Face} = .437D, \text{ mean ;}$$
$$= .300D, \text{ minimum ;}$$
$$= .650D, \text{ maximum.}$$

Cross-head pin.—Projected area varies from $.066A$ to $.346A$, the mean value being about $dl = .105A$. The length of pin was from d to $2d$, the mean being $l = 1.33d$.

Fly-wheel.—The weight of rim, W, should be proportional to $\frac{\text{H. P.}}{D_1^{\ 2} N^3}$ (in which D_1 is diameter of wheel in inches). A wide range of weights occurs here:

$$W = 833{,}000{,}000{,}000 \frac{\text{H. P.}}{D^2 N^3}, \text{ mean};$$

$$= 341{,}000{,}000{,}000 \frac{\text{H. P.}}{D^2 N^2}, \text{ minimum};$$

$$= 2{,}780{,}000{,}000{,}000 \frac{\text{H. P.}}{D^2 N^3}, \text{ maximum}.$$

General practice lies near the mean.

The linear velocity of rims was as an average about 4,200 feet per minute.

Weight of reciprocating parts.—The weight of reciprocating parts, W, should be proportional to $\frac{D^2}{LN^2}$. Taking the reciprocating parts as made up of the piston, piston-rod, cross-head, and one-half the connecting-rod as a mean,

$$W = 1{,}850{,}000 \frac{D^2}{LN^2}.$$

Weight of entire engine per horse-power.—The average weight of engine is

$W = 117(\text{H. P.} - 7)$, or $W = 117(\text{H. P.}) - 820$ pounds,

assuming the steam-pressure 100 pounds per square inch above exhaust-pressure.

THE EFFICIENCY AND ECONOMY of this class of engine have been already indicated to be superior to the simple engine in proportion to the reduction effected in the

amount of the internal wastes, very nearly. The economy due to placing the cylinders in series has also been seen to be, roughly stated, pretty nearly that of the simple engine—doing the same work at the same ratio of expansion—divided by the number of cylinders in series. The actual performance of an engine of good design, operated under fairly economical, and perhaps fair average, conditions will be given presently.

The absolute efficiency of the engine, as in all cases, and with all classes of heat-motors, is measured by the quotient of the work delivered in the assumed unit of time to the thermodynamic equivalent of the energy supplied, in steam or in fuel, or in thermal units. Thus, if the number of B. T. U. be measured per I. H. P. and per hour—since the thermal equivalent of the horse-power is 2,545 B. T. U. per hour for efficiency unit—the efficiency of the engine tested must be

$$\text{effic.} = 2{,}545/H,$$

where H is the quantity of heat demanded per horse-power and per hour. If W is the "water-rate" of the engine, the weight of steam or of feed-water supplied per horse-power and per hour under the conditions of the engine-trial, and if H_s is the quantity of heat per unit weight absorbed from the fuel, the efficiency, gauged by the steam-consumption, becomes

$$\text{effic.} = 2{,}545/WH\ ;$$

as, for example, if the steam take up, in the heater and the boiler, 1,018 B. T. U. per pound and transfer it to the

engine, the efficiency becomes, assuming 20 pounds per I. H. P. per hour, $12\frac{1}{2}\%$, thus :

$$\text{effic.} = 2{,}545/20{,}360 = 2{,}545/20 \times 1{,}018 = 0.125.$$

Similarly, if the fuel has a net value, in heat delivered to the boiler and utilized in making steam, of 10,180 B. T. U., which is not an exceptional figure, the efficiency becomes. at 2 pounds per I. H. P. per hour,

$$\text{effic.} = 2{,}545/2 \times 10{,}180 = 0.125.$$

The measurement of the indicator-diagram gives the quantity of dynamic energy developed, while that of the heat supplied by one or another of these methods gives the measure of the energy expended. The quotient of energy received by energy paid out, measured in similar terms, is the measure of the absolute efficiency of the system.

COMPUTATIONS OF THE PROBABLE EFFICIENCIES of the "Ideal Case" and of the Real Engine, basing the estimates of its wastes upon earlier experiments upon the same class of engine, are readily made by the methods of Rankine, supplemented by those of Hirn, the first to engage in this research.

It is proposed to compute the demand for heat and steam for the purposes of designer and purchaser, in the case of a simple engine, condensing, with 5 pounds back-pressure in the cylinder, on the assumption of the data given below ; the conditions as to waste being substantially those illustrated in the Sandy Hook experiments of 1884.

Pressures are taken from 75 to 155 pounds per square inch above the atmosphere, ratios of expansion from 1.6 to 16, and the engine as speeded at 280. External wastes of heat are assumed to average 0.5 B. T. U. per square foot of external surface and per degree range of temperature from atmospheric—here taken as 100° F. Internal wastes are taken as aggregating, as a fraction of the total steam supplied,

$$w = a\sqrt{rn}/a,$$

where the coefficient $a = 4$ in the case assumed to be fairly representative of that here considered; d is the diameter of cylinder in inches,[1] r the ratio of expansion,[2] and n the number of revolutions per *second*. Friction-wastes are taken as found for moderate cut-offs, efficiency of the engine as a machine being assumed at 0.85. Better work than this can be and should be done. J is taken as 778. The following are the assumed data:

DATA.

Cylinder 6″ × 10″; rev. 280; rated 10 I. H. P.

$p_1 =$	75	95	115	135	155
$p_3 =$	5	5	5	5	5
$r =$	1.6	2	4	8	16
$c = \frac{1}{r} =$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{16}$

Pressures are here measured from absolute zero.

1. Of the low-pressure cylinder in the case of the multiple-cylinder engine.
2. Of the cylinder of largest expansion in the case of the multiple-cylinder engine.

The work per cubic foot of steam is here computed by the familiar expressions of Rankine:

$$UD_1 = JD_1\left[T_1 - T_2\left(1 - \log_e \frac{T_1}{T}\right)\right] + \frac{T_1 - T_2}{T_1}H_1 - r(p_2 - p_3)$$

and

$$p_2 = UD_1/r.$$

An examination of the figures here collected will show in a most interesting manner the gradual variation of steam-consumption with change of expansion at each pressure; and a comparison of the figure for the several pressures will illustrate the interesting modifications of result due to variations of expansion with pressures, and the differences in the location of the best points of cut-off for these pressures. These instructive comparisons are best made by the construction of curves, of which the co-ordinates are, for each pressure, weights of steam demanded per horse-power and per hour at stated ratios of expansion. Such figures have been obtained by the computers for the present case, and are illustrated in the accompanying tables. It is seen that at the lowest pressure, 75 pounds, maximum economy of steam and fuel is attained at a cut-off very near $\frac{7}{32}$, or a ratio of expansion of about 4.5 when the dynamometric power is taken, or at about a cut-off of 0.2 and $r = 5$ on the basis of indicated power. These figures become about 3.16 and 5 at 95 pounds, $\frac{11}{64}$ and 6 at 115, $\frac{5}{32}$ and 6.4 at 135, and $\frac{9}{64}$ and 7 when the pressure becomes 155 absolute, cr 140 pounds by gauge.

This gradual shifting of the ratio of expansion giving

PERFORMANCE OF

WITH

Ratio of Expansion.	Cut-off.	Pressure, Pounds per Square Inch.	Temperature Absolute.	Density of Steam.	Latent Heat, Foot-pounds.	Terminal Pressure, Pounds per Square Inch.	Terminal Pressure, Pounds per Square Foot.	Terminal Temperature.
16	1-16	75	768.6	.175622	110,437	3.22	463.7	605.4
8	⅛	75	768.6	.175622	110,437	7.08	1,020	638.6
4	¼	75	768.6	.175622	110,437	15.55	2,239	676.0
2.7	⅜	75	768.6	.175622	110,437	24.29	3,498	699.7
2	½	75	768.6	.175622	110,437	34.15	4,918	719.0
1.6	⅝	75	768.6	.175622	110,437	44.00	6,336	734.2
16	1-16	95	785.1	.219430	151,336	4.08	588	615.0
8	⅛	95	785.1	.219430	151,336	8.97	1,292	649.4
4	¼	95	785.1	.219430	151,336	19.70	2,837	688.4
2.7	⅜	95	785.1	.219430	151,336	30.77	4,431	713.0
2	½	95	785.1	.219430	151,336	43.26	6,229	733.1
1.6	⅝	95	785.1	.219430	151,336	55.72	8,024	749.0
16	1-16	115	799.1	.262732	179,142	4.94	711.8	623.0
8	⅛	115	799.1	.262732	179,142	10.86	1,564	658.4
4	¼	115	799.1	.262732	179,142	23.84	3,433	698.6
2.7	⅜	115	799.1	.262732	179,142	37.25	5,364	724.0
2	½	115	799.1	.262732	179,142	52.36	7,540	745 0
1.6	⅝	115	799.1	.262732	179,142	67.46	9,714	761.5
16	1-16	135	811.2	.305659	206,386	5.80	835.6	630.0
8	⅛	135	811.2	.305659	206,286	12.75	1,836	666.2
4	¼	135	811.2	.305659	206,286	27.99	4,031	707.6
2.7	⅜	135	811.2	.305659	206,286	43.73	6,297	733.9
2	½	135	811.2	.305659	206,286	61.47	8,852	755.3
1.6	⅝	135	811.2	.305659	206,286	79.19	11,403	772.4
16	1-16	155	822	.348265	232,738	6.66	959.4	635.80
8	⅛	155	822	.348265	232,738	14.63	2,106	673.0
4	¼	155	822	.348265	232,738	32.14	4,628	715.3
2.7	⅜	155	822	.348265	232,738	50.20	7,223	742.3
2	½	155	822	.348265	232,738	70.58	10,163	764.5
1.6	⅝	155	822	.348265	232,738	90.92	13,092	782.0

1. For multiple-expansion engines of similar power these wastes may be divided by the number of cylinders in series to obtain an approximate measure of these

SMALL HIGH-SPEED ENGINE.

CONDENSATION.

Indicated Power.	Steam per I. H. P. per Hour (Ideal).	Internal Waste Coefficient.	Internal Waste, Pounds per I. H. P. and per Hour.[1]	External Waste, Pounds per I. H. P. and per Hour.	Total Waste, Pounds per I. H .P. and per Hour.	Total Consumption, Pounds per I. H. P. and per Hour.	Same per D. H. P.
3.100	*15.85*	1.234	19.56	3.30	22.86	38.71	45.54
6.42	*15.32*	.87287	13.37	1.50	14.93	*30.25*	*35.58*
11.77	*16.72*	.61720	10.32	.847	11.167	*27.887*	*32.80*
14.97	*18.48*	.50710	9.88	.666	10.546	*30.026*	*35.32*
17.85	*21.44*	.43650	9.71	.555	10.265	*32 51*	*38.24*
19.90	*24.76*	.3900	9.66	.502	10.162	*34.92*	*41.08*
4.83	*12.74*	1.234	15.73	1.663	17.393	30.133	35.45
9.31	*13.21*	.87287	11.53	.969	12.499	*25.71*	*30.24*
15.97	*15.42*	.61720	9.09	.666	9.656	*25.076*	*29 50*
20.58	*17.72*	.50710	8.99	.428	9.418	*27.14*	*31.93*
24.20	*20.34*	.43650	8.88	.375	9.255	*29.595*	*34.81*
26.62	*23.11*	.3900	9.02	.333	9.353	*32.46*	*38.19*
6.18	*11.91*	1.234	14.70	1.360	16.060	27.97	32.91
11.62	*12.68*	.87287	11.07	.755	11.825	*24.55*	*28.82*
19.68	*14.97*	.61720	9.24	.415	9.655	*26.48*	*28.97*
25.28	*17.35*	.50710	8.80	.331	9.131	*28.836*	*31.15*
29.64	*19.88*	.43650	8.68	.276	8.956	*30.00*	*33.92*
32.60	*22.60*	.3900	8.82	.251	9.071	*31.66*	*37.26*
7.534	*11.38*	1.234	14.05	1.043	15.093	26.473	31.14
13.91	*12.32*	.87287	10.75	.504	11.314	*23.63*	*27.80*
23.37	*14.67*	.61720	9.05	.344	9.394	*24.06*	*28.30*
30.00	*16.96*	.50710	8.60	.263	8.863	*25.82*	*30.37*
35.00	*19.54*	.43650	8.53	.236	8.756	*28.29*	*33.28*
38.50	*22.25*	.3900	8.68	.208	8.888	*31.13*	*36.62*
8.89	*10.98*	1.234	13.55	.836	14.336	25.36	28.84
16.20	*12.05*	.87287	10.52	.462	10.982	*23.03*	*27.09*
27.00	*14.41*	.61020	8.89	.274	9.164	*23.57*	*27.73*
34.58	*16.72*	.50710	8.48	.213	8.693	*25.41*	*29.89*
40.50	*19.28*	.43650	8.41	.182	8.592	*27.87*	*32.74*
44.48	*21.95*	.3900	8.57	.164	8.344	*30.68*	*36.26*

losses in such engines. It will be noted that the back-pressure and, consequently, lost work during the exhaust, are here made somewhat high.

highest economy of fuel and of steam is better illustrated in the last set of curves, in which two exhibit the variation of this point of cut-off with varying pressures, while the other pair show the progressive gain in economy of fuel and of steam in a similar manner; the numerical values of the former quantities increasing, and the latter decreasing, with rising steam-pressure. The weight of steam consumed is not far, at best, from

$$w = 250/\sqrt{p}$$

pounds of steam per hour per indicated horse-power when working under best conditions, and the best ratio of expansion, on the same basis, is about

$$r = 0.5\sqrt{p}.$$

The conditions here assumed may be taken as fairly representative of good practice with such an engine in moderate sizes. Where leakage occurs or when compression is incomplete and the clearances thus become sources of additional wastes, these figures may be much exceeded. Larger engines will be less subject to waste, and the margin between the ideal case and the actual may be thus reduced approximately in proportion to increasing size of engine.

The economically desirable ratio of expansion and point of cut-off, however, are always somewhat less than are found to give lowest expenditure of steam and fuel, since every item of cost in the construction of the engine involves a corresponding annual charge thereafter, and a compromise

between increasing annual expense on this count and decreasing cost of fuel must be made to secure the best results.

The commercially desirable ratio of expansion is always less than that giving maximum duty; but the margin between the two depends greatly upon he relative costs of construction and of operation of engine and boiler and cost of fuel. Methods of exact computation are becoming developed and approximate methods are well known.[1] In general, at the commercial centers the ratio to be adopted in designing will not be far from two-thirds that here found to give best effect for the ideal case, twenty per cent lower than is shown on the diagrams for the actual case, and still lower where it is sought to make the most out of an engine already set and in operation.

THE DISTRIBUTION OF ENERGY supplied the steam-engine is easily stated in a general way; but the exact distribution into utilized power and wasted energies is not always readily ascertainable, even with modern facilities for their measurement. Assuming this analysis to have been effected in any given case, as for a modern "high-speed" engine of moderate power and working with high steam-pressure, some such balance-sheet as the following would be obtainable. Should the columns fail to balance, it would indicate either that a false measurement had been made, that the errors of careful observation, even, were sensible and perhaps cumulative, or that some source of waste had escaped observation altogether, as often did, in fact, the internal

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1. Manual of Steam Engine, Vol. I. Chap. VII.

thermal wastes during the greater part of the history of the machine and up to within a few years.

BALANCE-SHEET OF HIGH-SPEED ENGINE.

RECEIVED.	Per Cent.	EXPENDED.	Per Cent.
Energy stored in steam produced in the boiler and transferred to the engine	100	Utilized by conversion into dynamic energy at the engine	9
		Wasted by friction . . .	1
Total	100	Indicated power	10
		External thermal waste .	2
		Thermodynamic wastes .	60
		Internal thermal waste . .	28
		Total	100

In the figure let the ordinates of the various curves be made proportional to the weights of steam employed per horse-power and per hour under the conditions assumed in the construction of each of the several curves, and let the abscissæ measure the simultaneous values of the ratios of expansion in the given engine, and with the initial and back pressures as here assumed—120 and 3 pounds, respectively, above vacuum. Compute, first, the quantity of steam required for the "ideal case" at each of these ratios of expansion, and construct the lower curve of the series by passing it through the several computed points. Similarly, compute, or find by reference to results of experiment, the additional and total quantities demanded for the engine when the wastes due friction are taken into account, and thus obtain the second curve. Next add the weights of steam required to supply the heat wasted externally by

conduction and radiation, and, as a final determination, find the internal wastes by the action of the cylinder-walls, thus ascertaining the locus of the upper limiting curve of the series.

The lower line is obtained by the method of Rankine, and accurately represents the efficiencies and the costs of power for the ideal representative case taken. It is seen that the steam expended varies from about 40 pounds per horse-power and per hour at full stroke to 20 at 3.5 expansions, to 16 at a ratio of expansion of 5, to 12 at 12 expansions, and to about 10 pounds at a ratio of 20. The gain continues indefinitely, but at a decreasing rate, until a ratio of about 40 brings us to the limit at which the expansion-line begins to fall below the back-pressure line. Were there no wastes of extra thermodynamic character, this would be the method of operation of the engine which would insure highest efficiency and highest "duty." The friction loss in the case here taken costs a quantity of steam which is decreased with the enhanced efficiencies of higher expansions, is but little affected by changing loads and power, and which, as a percentage of ideal costs, increases constantly with increasing expansion and decreasing power. It is thus found to place a limit to gain, as here taken, at about twenty-five expansions and adds, throughout the whole range, not far from three pounds of steam per hour and per horse-power to the costs of useful work. External heat wastes still further exaggerate costs and restrict the profitable expansive action of the engine, and a ratio of 20 is found on the curve to be as much as can be employed to advantage when all these wastes are taken into

account. Finally, taking up the internal heat wastes by action of the metallic surfaces enclosing the fluid, and assuming, as here, that the engine is of such size and character as to waste, in spite of jacket-action, from twenty per cent at full stroke to fifty per cent at seven expansions, and still higher proportions at greater ratios, the proportions found actually wasted in, for example, the Sandy Hook experiments reported by the writer to the A. S. M. E. some years ago, it is found that a maximum efficiency is attained, as shown on the upper line, at about seven expansions, or at the point experimentally found for a more efficient engine, operated at a lower pressure, by Hirn and Hallauer. This is probably as large a loss, and gives as radical an illustration of the facts of such cases, as can be fairly expected.

Whatever the form or dimensions of the engine, such construction of its several elements of efficiency as is here exemplified will exhibit the facts in which the designer is most interested, and show the costs of power and the most economical adjustment for high duty. All the thermodynamic and all the thermal and all the dynamic elements are here brought into view, and all measures are taken by a common and intelligible scale.

Every essential element of economical operation being thus capable of representation on a common scale, the construction of such a diagram as is here illustrated and described for each permits the selection of the machine likely, on the whole, to prove best; and we are thus enabled to identify the best adjustment of each and to make the comparison of a pair or of a series of available designs under

their several individually best conditions of working. Adhering to the case thus far studied, that of the simple engine, it may be required to ascertain which of a number of machines of stated and required power, but differing in proportions of stroke and diameter of cylinder, or in speed of piston and of rotation, or even simply in clearance, is most desirable. The construction, on a common scale, of a set of these diagrams will reveal to the eye and at a glance the probably best design. The loss by clearance is treated precisely like the wastes by external loss of heat or by internal condensation or leakage, and all may, as in fact illustrated above, be taken as a common internal waste since it often happens, as here, that they cannot well be separated with exactness. The best practical method of making the comparison is perhaps that of making the diagrams on tracing-paper or cloth and superposing them, one upon the other, in pairs, eliminating, one after another, the least desirable cases.

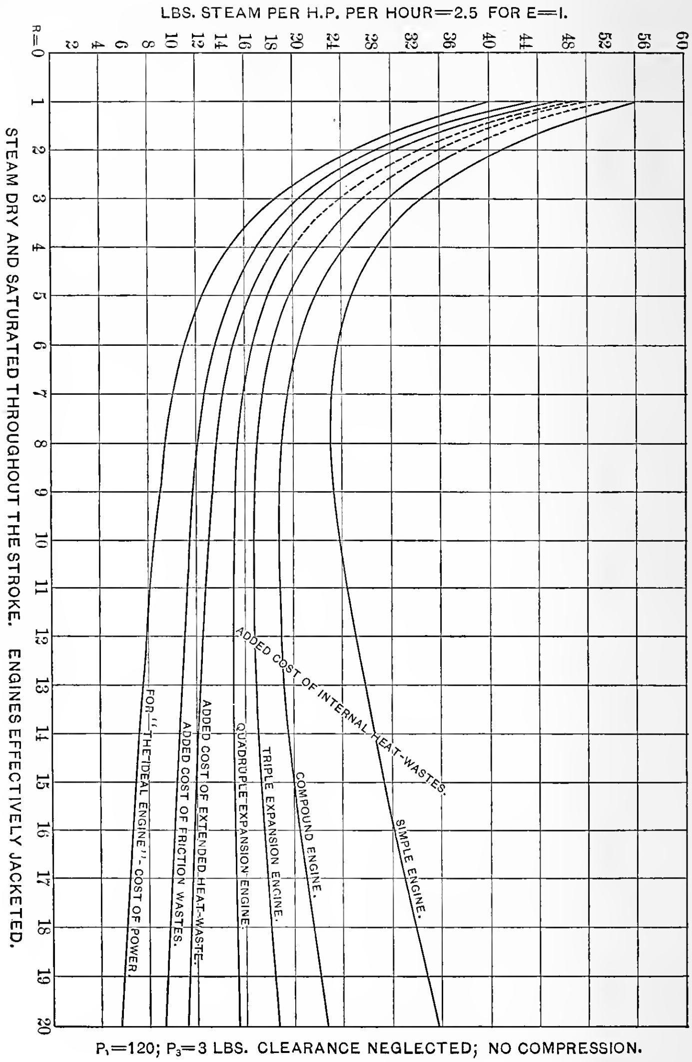
Compound or "Multiple-expansion" Engines afford the most interesting and probably the most useful applications of such methods of graphical representation of problems of this sort. In such comparisons as have been just referred to, when multiple expansion, series expansion—or cascade expansion, as French writers sometimes call it—is to be considered, it becomes especially important to ascertain not only what relations of efficiency exist at the best adjustment of each, but often even more important to determine the method of variation of efficiencies with varying expansion, and the relative values of each type throughout their respective as well as their common ranges of working.

This process of complete study, which, ordinarily is most laborious and troublesome—when, especially, their respective best conditions of operation are to be identified and compared—becomes easy, interesting, and exact when the graphical process can be accurately carried into effect. It then becomes as easy to discover the best ratios of expansion, and the ranges of working throughout which the simple engine is inferior or the more complex structure is superior, as to find absolute values for specified single cases. But it is in the exhibition of the relative values of the several multiple-cylinder engines that this process is perhaps likely to prove of most service and to best illustrate the essential principles involved.

In the action of the multiple-expansion systems the several lines of our diagram become altered in location, although retaining their distinctive forms. The ideal case only remains unaffected, the thermodynamic conditions being the same. The friction-line is usually, but not always or necessarily, raised; the friction of the machine being in some cases substantially unaltered, and in others even reduced, by modifications of designs introduced by "compounding." In the "tandem-compound" engine this change is often insensible or unimportant; in the three-crank compound this dynamic waste may be even reduced by the balance secured about the shaft-line. The external thermal wastes may be but slightly affected also, the reduction of the mean temperature of the external surfaces of the cylinders compensating roughly the extension of area.

The internal heat wastes are most remarkably modified in good examples of such engines. The upper line of our

diagram is brought down considerably and often very far below that location given it in the case of the companion simple engine. These wastes may be reduced from six or eight pounds, for example, to three or four in the compound, to two or three in the triple-expansion, or to even less weight of steam per horse-power and per hour in the more complicated forms of engine, for similar total ratios of expansion. The restricted expansion in each of the cylinders and the reduced area of actively wasteful cylinder-wall make the condensation of the entering steam much less than at the point of cut-off in the simple engine, and the steam thus condensed, being re-evaporated completely at its exit, enters the second cylinder in series as steam once more, is there again subjected to similar condensation, and thus goes on through the series, however extensive, the waste from the one cylinder more or less completely meeting the demand for wastes in the next, and thus approximately reducing the total waste from this action to that comparatively small fraction of the steam supplied from the boiler which is represented by the comparatively small condensation in a single cylinder of the series. Every step thus gained in the reduction of these internal thermal wastes permits corresponding advance to be made toward full utilization of the thermodynamic gain due expansion and raises the ratio of expansion for best effect. Following experience with the most successful designs of mill-engines, and comparing cases in which the double-expansion engine reduces the internal wastes to one-half, the triple to one-third, and the quadruple to nearly one-fourth the magnitudes distinguishing our simple machine, we obtain the


LBS. STEAM PER H.P. PER HOUR=2.5 FOR E=1.
2 4 6 8 10 12 14 16 18 20 24 28 32 36 40 44 48 52 56 60
R=0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
STEAM DRY AND SATURATED THROUGHOUT THE STROKE. ENGINES EFFECTIVELY JACKETED.
ADDED COST OF INTERNAL HEAT-WASTES.
FOR "THE IDEAL ENGINE"-COST OF POWER.
ADDED COST OF FRICTION WASTES.
ADDED COST OF EXTENDED HEAT-WASTE.
QUADRUPLE EXPANSION ENGINE.
TRIPLE EXPANSION ENGINE.
COMPOUND ENGINE.
SIMPLE ENGINE.
P1=120; P3=3 LBS. CLEARANCE NEGLECTED; NO COMPRESSION.

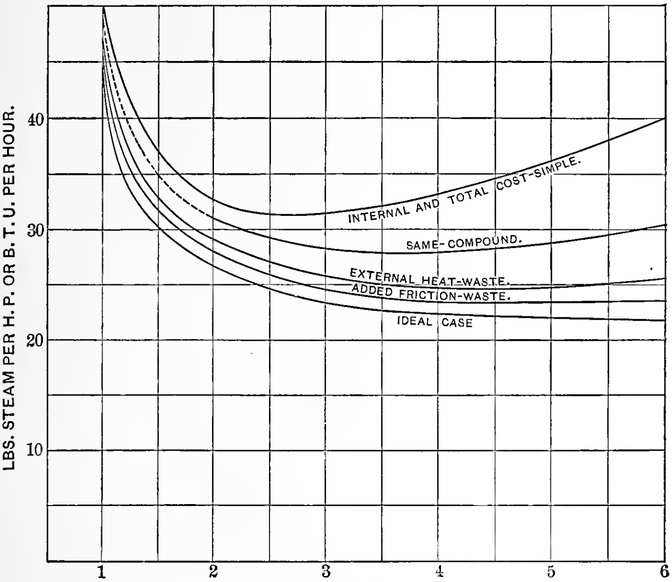
three curves in the figure, page 250, lying between the upper line already obtained and the lower three lines of the diagram as first traced.

In each case we find the internal heat wastes constituting a heavy tax upon the operation of the engine ; in each they become a larger proportion of total expenditures as the ratio of expansion becomes greater ; in each case the point of minimum expenditure and the ordinate of maximum efficiency recede further from the best ordinate for the simple machine as these losses become less ; and, as already remarked, the ratio of expansion for highest total effect becomes a gauge of the value of the type of engine studied. While the simple engine did its best work at a ratio of 7—all these machines are assumed to be jacketed—the compound raises the figure to 10, the triple-expansion to 12 or 13, and the quadruple-expansion engine does its best duty at a ratio not far from 18. With larger and faster engines these values of the ratio of maximum effect will be found still more distributed and will assume still higher values ; but 7 or 8, 10 to 12, 13 to 15, and 18 to 20 are probable fair maxima, respectively, in modern good practice with the assumed pressure, for the several types of machine above taken.

Comparing the range of competitive operation, it is seen that in these particular cases the compound competes with the simple throughout the range from the ratio 4 to some point beyond our maximum limit on the diagram ; that the triple-expansion competes with the compound from $r = 5.5$, and with the simple between 3.5 and the maximum; and that the quadruple similarly competes with the simple

between 3 and the limit, with the triple between 5 and the extreme, and with the compound between 3.75 and 20 or more. It is assumed in each comparison that the basis of the competition is the duty, or the steam required per horse-power per hour. The simple engine competes, at its best ratio, with the compound and other engines only when the latter are working at abnormally low ratios of expansion, and each multiple-cylinder machine shows superiority over the preceding in our list at expansions which are always less than the best ratios of the simpler engine. These comparisons, however, obviously may result very differently when the complication introduced with the multiple-cylinder engine throws up the lines representing friction and external wastes to such height as to make the loss of energy in these directions exceed the gain by reduced internal wastes, and thus carries the upper line of the representative diagram for the latter above the line of total cost for the simpler machine with which it is compared. Very different and often very disappointing and unexpected results may thus follow where the engines are not suitably adapted to their working conditions, or when they are unskilfully designed and proportioned.

In all cases, whatever the type of engine, it is likely to be found that the best results are only to be secured when the extra thermodynamic wastes of the machine are intelligently treated and made as small as practicable. It is in this direction that the indications are that the greatest advances are to be made in the immediate future of the history of the steam-engine.



HIGH-SPEED, SINGLE VALVE ENGINE.

SIMPLE ENGINE UNJACKETED. COMPOUND ENGINE JACKETED.
Steam at $p_1 = 120$ lbs. absolute ; $p_3 = 20$.

SPECIFIC APPLICATIONS of the principles illustrated in the general case just presented will be easily effected where the data are available. For example, let the preceding figure represent the distribution of useful energies and wastes in the case of a high-speed engine with single valve. The thermodynamic case is computed as per Rankine and as in the earlier work of the author.[1] The steam-consumption is found by experiment to be approximately measured by $w = 45/\sqrt{r}$. This quantity is increased, when the friction

1. Rankine, p. 192 *et seq.;* Thurston's Manual, Vol. I. Arts. 116, 117, and especially 123, 137.

of the engine is taken into account, by about ten per cent at ordinary expansions, and the external heat wastes add a very nearly equal amount, both these wastes, however, being found by experience to be variable slightly with varying power and to be somewhat less as an absolute amount and greater relatively with decreasing expansion. Friction is taken as six per cent of the full power at full stroke, heat waste as 0.5 B. T. U. per square foot per hour per degree difference of temperature between the internal and the external temperatures. Adding the internal wastes by condensation, leakage, clearance, and wire-drawing, following Clark for the first-mentioned up to the middle of our range and later practice beyond, we obtain the upper curve and find our profitable expansion restricted to about $r = 2.5$; which accords with general experience from Clark's earliest work to the present time. But should these last wastes be decreased by compounding or superheating, as is known to be practicable, to one-half their present amount, the limit-curve would fall to the second line, and the allowable ratio of expansion for highest duty and lowest consumption of fuel in regular work would fall correspondingly, giving a higher ratio $r = 4$ or 5, and a consumption of fuel or of steam more nearly 3 than 4, and 25 than 32, as the first set of figures would probably read. In other words, the gain would be not far from twenty-five per cent. Both the first and last results have been bettered by engines of each type; but the relative standing of the two should be very much as here indicated.

Financial Conditions, as was shown by Rankine as early as the middle of the nineteenth century, are the final limit-

ing considerations in adjusting the power of an engine and its method of expansion to secure the best possible results in any given location and in stated conditions of the market for labor and material.

It is easy to see that if the vertical scale of our diagrams were, as it might perfectly well be made, one of dollars instead of weight of steam we might superpose upon the series of curves constituting each another, which should represent the varying costs of power external to the engine- and the boiler-plant, those costs which measure the annual value of capital invested and expenses incurred, apart from the internal costs of production of the power,—such as, for example, in the former class, the interest on costs of engine, boiler, buildings, etc.,—and on the same scale which would measure the costs of the steam-supply already treated of. Referring to the first set of curves, assume the next to the upper line to represent these "internal" costs and the upper curve to measure the "external" expenses, it is here seen that, as is the known fact, the latter being an increasing relative magnitude, the departure of the pair of curves from each other with increasing expansion indicates that these new considerations dictate still further restriction of the ratio of expansion and still further narrow the range of nearly constant economy. As is elsewhere shown by the author, this restriction is often more effective than even the enormous influence of internal wastes has been seen to prove. Where the designer seeks to ascertain what adjustment will give him the best work in proportioning an engine of either class to perform a specified amount of work, he often finds it necessary to adopt a ratio of expansion not

exceeding two-thirds that dictated by the solution of the problem above studied.[1]

PERFORMANCE UNDER TEST, as illustrated in the trial of this class of engine, may be gauged by the following data and results of an engine-trial made in the usual manner, the engine being of 15 to 20 horse-power, compound and condensing, and of the dimensions given below. With larger, faster, or better designed, and especially better protected, engines wastes may be reduced somewhat below those stated, and correspondingly nearer approximations effected to the goal sought by the engineer in designing economical engines—i.e., to the performance of the ideal machine.[2]

DIMENSIONS OF ENGINE.

Diameter of high-pressure cylinder	12 in.
Diameter of low-pressure cylinder	20 "
Length of stroke (nominal)	14 "
Length of stroke (measured)	13.97 in.
Length of stroke (measured)	1.164 ft.
Diameter of piston-rod	1.9375 in.
Area of high-pressure piston, head	113.098 sq. in.
Area of high-pressure piston, crank	110.149 sq. in.
Area of low-pressure piston, head	311.211 " "
Area of low-pressure piston, crank	311.211 " "
Piston displacement, high-pressure, head	.91425 cu. ft.
Piston displacement, high-pressure, crank	.89042 " "
Piston displacement, low-pressure, head	2.51575 " "
Piston displacement, low-pressure, crank	2.51575 " "
Clearance, high-pressure cylinder, head	.15716 " "
Clearance. high-pressure cylinder, crank	.14718 " "
Clearance, low-pressure cylinder, head	.31422 " "
Clearance, low-pressure cylinder, crank	.31925 " "

1. Manual of the Steam Engine, Vol. I. Chap. VII.
2. Thurston's Manual of the Steam Engine, Vol. I. p. 398, and Chap. V. § 129–131.

Clearance, per cent of stroke, high-pressure cylinder, head	17.50
Clearance, per cent of stroke, high-pressure cylinder, crank	16.20
Clearance, per cent of stroke, low-pressure cylinder, head	7.40
Clearance, per cent of stroke, low-pressure cylinder, crank	7.60
Volume of receiver-space	1.1455 cu. ft.
Volume of space in pressure-plate	.12819 " "
Volume of space in pressure-plate, per cent of stroke	5.09

The engine is a "tandem compound." The computations of probable wastes, on the assumed basis previously taken, of correspondence with those of the Sandy Hook experiments, would give figures, reduced to expenditures per horse-power and per hour, as on page 258, about one-half those of the smaller engine referred to on page 238,[1] and would, with ten per cent friction, be as follows :

At the lowest pressure, 75 pounds, maximum economy of steam and fuel is found at a cut-off very near $\frac{7}{32}$, or a ratio of expansion of about 4.5, when the dynamometric power is taken, or at about a cut-off of 0.2 and $r = 5$ on the basis of indicated power. These figures become about 3.16 and 5 at 95 pounds, $\frac{11}{64}$ and 6 at 115, $\frac{5}{32}$ and 6.4 at 135, and $\frac{9}{14}$ and 7 when the pressure is 155 absolute, or 140 pounds by gauge.

The wastes average four or five pounds. The details of the machine need not be here given.[2] It is only necessary to say that the machine is carefully balanced, has good

1. See Manual, Chaps. V.–VI.
2. For details see Manual of the Steam Engine, Vol. I. Art. 35, p. 142.

EFFICIENCIES OF HIGH-SPEED ENGINE.

r	Cut-off.	Pressure, Pounds per Square Inch.	Steam per I. H. P. per Hour (Ideal) W.	Total Waste, Pounds per I. H. P. and per Hour.	Total Consumption, Pounds per I. H. P. and per Hour.	Same per D. H. P. Machine Eff., 0.90.
16	1-16	75	*15.85*	11.5	27.35	30.6
8	⅛	75	*15.32*	7.5	*22.82*	*25.4*
4	¼	75	*16.72*	5.5	*22.22*	*26.7*
2 7	⅜	75	*18.48*	5.3	*23.78*	*26.4*
2	½	75	*21.44*	5.3	*26.74*	*29.7*
1.6	⅝	75	*24.76*	5.2	*29 96*	*33.3*
16	1-16	95	*12.74*	8.7	21.44	23.8
8	⅛	95	*13.21*	6.2	*19.41*	*21.6*
4	¼	95	*15.42*	4.8	*20.26*	*22.5*
2.7	⅜	95	*17.72*	4.7	*22 42*	*22.7*
2	½	95	*20.34*	4.6	*24 14*	*27.0*
1.6	⅝	95	*23.11*	4.6	*27.71*	*30.8*
16	1-16	115	*11.91*	8.0	19.91	22.1
8	⅛	115	*12.68*	5.9	*18.58*	*20.6*
4	¼	115	*14.97*	4.8	*19.77*	*22.0*
2.7	⅜	115	*17.35*	4.6	*21.95*	*24.4*
2	½	115	*19.88*	4.5	*24.38*	*27.1*
1.6	⅝	115	*22.60*	4.0	*26.60*	*29.9*
16	1-16	135	*11.38*	7.5	18.88	21.0
8	⅛	135	*12.32*	5.6	*17.92*	*19 9*
4	¼	135	*14.67*	4.7	*19.37*	*21.5*
2.7	⅜	135	*16.96*	4.4	*21.36*	*23.7*
2	½	135	*19.54*	4.4	*23.94*	*26.5*
1.6	⅝	135	*22.25*	4.4	*26.65*	*29.6*
16	1-16	155	*10.98*	7.1	18 08	20.1
8	⅛	155	*12.05*	5.5	*17.55*	*19.5*
4	¼	155	*14.41*	4.6	*19.01*	*21.0*
2.7	⅜	155	*16.72*	4.4	*21.12*	*21.1*
2	½	155	*19.28*	4.3	*23.58*	*25.1*
1.6	⅝	155	*21.95*	4.1	*26.05*	*28.9*

provisions for free lubrication, and in the only case in which the writer has had extended experience with it[1] has shown itself an excellent example of its class.

The following are the results of trial :

DATA AND RESULTS.

Time of starting	6.45 P.M.
Time of stopping	11.45 "
Duration of trial	5 hours.
Total number of revolutions (per continuous counter)	60300
Revolutions per minute	201
Barometer in inches of mercury	29.40
Atmospheric pressure	14.50 pounds.
Boiling-temperature at atmospheric pressure	211°.10
Boiler-pressure by gauge	98.00 pounds.
Boiler-pressure, absolute	112.50 "
Pressure in steam-chest, low-pressure cylinder	34.00 "
Vacuum-gauge, inches of mercury	22.99
Temperature of condensed steam	130°.8
Temperature of injection-water	47°.9
Temperature of discharge-water	106°.7
Temperature in calorimeter, steam-pipe	212°.8
Quality of steam in steam-pipe	95.50 per cent.
Quality of steam in compression (assumed)	100.00 "
Quality of steam in exhaust	93.30 "
Total weight of condensed steam	11594.50 pounds.
Pounds of wet steam per stroke, mean	.0961484
Pounds of wet steam per stroke, head	.103593
Pounds of wet steam per stroke, crank	.088704
Cubic feet of condensing-water per minute (by meter)	9.304
Pounds per revolution	3.033
Pounds per stroke, head	1.634

1. An engine of this kind was built in the shops of Sibley College, Cornell University, and has now for several years done good work driving dynamos for experimental work in the Department of Physics, and later in furnishing power in the electric-light and power station.

Pounds per stroke, crank	1.399
Length of brake arm	8.07 feet.
Gross weight on brake-scale	367.00 pounds.
Net weight on brake-scale	323.75 "
Available delivered horse-power	99.99

	Head.	*Crank.*	*Total.*
M. E. P., high-pressure cylinder	30.096	26.460	—
M. E. P., low-pressure cylinder	16.854	13.729	—
I. H. P., high-pressure cylinder	24.132	20.664	44.796
I. H. P., low-pressure cylinder	37.188	30.294	67.482

Total I. H. P.	112.28
Total D. H. P.	101.17
Efficiency, per cent	90.16

Total weight of wet steam	11595.50 pounds.
Weight of wet steam per hour	2319.10 "
Weight of dry steam per hour	2234.72 "
Weight of steam per I. H. P. per hour	*19.903* "
Weight of steam per D. H. P. per hour	*22.35* "

HIRN'S ANALYSIS—DATA.

High-pressure Cylinder.

	End.	
	Head.	*Crank.*
Cut-off, per cent of stroke	26.40	19.83
Release, per cent of stroke	75.17	62.91
Compression, per cent of stroke	12.56	12.56
Absolute pressure at cut-off	105.30	104.50
Absolute pressure at release	56.00	49.00
Absolute pressure at compression	49.00	46.00
Absolute pressure at admission	73.00	81.00
Volume in cubic feet at cut-off	.40045	.32673
Volume in cubic feet at release	.76313	.70351
Volume in cubic feet at compression	.27210	.25903
Volume in cubic feet at admission	.15716	.14718
External work B. T. U., admission	4.9000	3.5958
External work B. T. U., expansion	5.0681	4.8380
External work B. T. U., exhaust	3.4571	2.5497
External work B. T. U., compression	1.2419	1.2749

	End.	
	Head.	*Crank.*
External work B. T. U., total........	5.2692	4.6092
Steam from boilers, pounds..........	10.3593	8.8704
Steam in clearance, pounds..........	2.6906	277.91
Steam, total, pounds	13.0499	11.6495
Heat in exhaust	11373.70	9738.80
Heat supplied to engine	12220.95	10316.00
Sensible heat at admission..........	741.45	785.99
Internal heat at admission..........	2207.16	2264.20
Sensible heat at cut-off............	3940.42	3510.80
Internal heat at cut-off	7747.50	6279.00
Sensible heat at release............	3363.00	2901.30
Internal heat at release............	8490.55	6959.30
Cylinder loss during admission	2991.64	3216.82
Cylinder loss during expansion......	672.44	554.60
Cylinder loss during exhaust	2535.37	2737.76
Cylinder loss during compression	536.51	181.83

Low-pressure Cylinder.

Cut-off, per cent of stroke............	36.18	24.48
Release, per cent of stroke...........	88.23	87.72
Compression, per cent of stroke.......	33.82	22.80
Absolute pressure at cut-off...........	25.50	26.50
Absolute pressure at release..........	12.00	9.70
Absolute pressure at compression.....	3.00	3.00
Absolute pressure at admission.......	22.00	19.00
Volume in cubic feet at cut-off	1.2209	.92491
Volume in cubic feet at release........	2.3974	2.3752
Volume in cubic feet at compression....	1.0359	.76953
Volume in cubic feet at admission.....	.3142	.3192
Volume in cubic feet of space in pressure-plate........................	.12819	.12819
External work B. T. U., admission.....	5.4233	3.5390
External work B. T. U., expansion....	4.1360	4.3582
External work B. T. U., exhaust......	.4109	.5811
External work B. T. U., compression..	1.5339	.9773
Total................................	7.6146	6.3388
Steam from boiler, pounds............	10.3593	8.8704

	End.	
	Head.	*Crank.*
Steam-clearance, pounds	1.7418	1.5387
Steam, total, pounds	12.1011	10.4091
Heat of condensed steam	1023.50	876.40
Condensing-water, pounds	108.937	93.279
Heat given to condensing-water	9608.30	8227.20
Heat supplied to engine	11373.70	9738.80
Sensible heat at admission	351.51	298.39
Internal heat at admission	1528.00	1362.50
Sensible heat at cut-off	2599.20	2208.30
Internal heat at cut-off	6768.20	5324.50
Sensible heat at release	1980.00	1611.70
Internal heat at release	6783.50	5694.20
Total heat in steam at beginning of compression	935.66	695.07
Heat confined in pressure-plate	521.69	465.36
Cylinder loss during admission	3343.48	3512.99
Cylinder loss during expansion	331.39	674.28
Cylinder loss during exhaust	2763.37	2434.66
Cylinder loss during compression	268.77	402.73

SUMMARY OF RESULTS.

High-pressure Cylinder.

	End.	
	Head. Per Cent.	*Crank. Per Cent.*
Heat lost by initial condensation	24.48	31.18
Heat restored during expansion	5.50	5.38
Heat rejected during exhaust	20.75	28.11
Heat lost during compression	4.39	1.76
Heat utilized, work (actual efficiency)	4.31	4.47
Thermodynamic efficiency	8.77	8.77
Efficiency compared with ideal	49.10	50.90
Quality of steam entering (per calorimeter)	95.50	95.50
Quality of steam at cut-off (computed)	74.19	67.33
Quality of steam at release (computed)	78.01	71.07
Quality of steam at admission (assumed)	100.00	100.00
Quality of steam in exhaust (computed)	104.00	104.00

LOW-PRESSURE CYLINDER.

	End: *Head* *Per Cent.*	*Crank.* *Per Cent.*
Heat lost by initial condensation	29.40	36.07
Heat restored during expansion	2.91	6.92
Heat rejected during exhaust	24.30	25.00
Heat lost during compression	2.36	4.13
Heat utilized, work (actual efficiency)	6.69	6.51
Thermodynamic efficiency	15.66	15.66
Efficiency compared with ideal	42.70	41.56
Quality of steam entering (per calorimeter)	93.30	93.30
Quality at cut-off (computed)	64.22	50.63
Quality at release (computed)	64.76	54.00
Quality at admission (assumed)	100.00	100.00
Quality of steam in exhaust (computed)	90.12	102.00

Averaging the given values for the head and crank ends for each of the two cylinders, the following values are obtained :

	Cylinders: *H.-p.* *Per Cent.*		*L.-p.* *Per Cent.*
Quality of steam entering (per calorimeter)	95.50		93.30
Quality of steam at cut-off (computed)	70.76		57.42
Quality of steam at release (computed)	74.54		59.38
Quality of steam at admission (assumed)	100.00		100.00
Quality of steam in exhaust (computed)	104.00		96.06
Heat lost by initial condensation	27.83		32.73
Heat restored during expansion	5.44		4.91
Heat rejected during exhaust	24.43		24.65
Heat lost during compression	3.07		3.24
Heat utilized, work (actual efficiency)	4.39		6.60
Total		10.99	
Thermodynamic efficiency	8.77		15.66
Total		24.43	
Efficiency compared with ideal	50.00		42.13
Mean		46.07	

POWER TABLE—"AUTOMATIC" ENGINE.

CUTTING OFF STEAM AT $\frac{1}{4}$ STROKE.

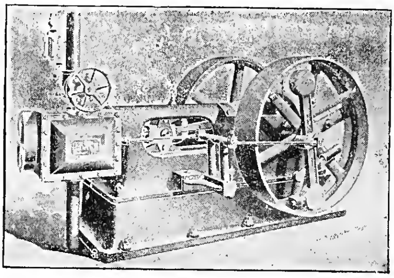
Size of Engine.	Constant.	Revolutions per Minute.	Initial Steam-pressure.					
			50	60	70	80	90	100
7″ × 9″	.00175	300 340	13.1 14.8	15.7 17.8	18.3 20.8	21.0 23.8	23.6 26.7	26.2 29.7
8″ × 9″	.00229	300 340	17.1 19.4	20.6 23.3	24.0 27.3	27.4 31.1	30.9 35.0	34.3 38.9
8½″ × 10½″	.00302	270 310	20.3 23.4	24.4 82.0	28.5 32.7	32.6 37.4	36.6 42.1	40.7 46.3
9½″ × 10½″	.00376	270 310	25.3 29.1	30.4 34.9	35.5 40.7	40.6 46.6	45.6 52.4	50.7 58.2
10″ × 12″	.00476	250 290	29.7 34.5	35.7 41.4	41.3 48.3	47.6 55.2	53.5 62.1	59.5 69.0
11″ × 12″	.00576	250 290	36.0 41.7	43.2 50.1	50.4 58.4	57.6 66.8	64.8 75.1	72.0 83.5
12″ × 15″	.00857	210 250	44.9 53.5	53.9 64.2	62.9 74.9	71.9 85.7	80.9 96.4	89.9 107.1
13″ × 15″	.01005	210 250	52.7 62.8	63.3 75.3	73.8 87.9	84.4 100.5	95.0 113.0	105.5 125.5
14½″ × 17″	.01417	200 240	70.8 85.0	85.0 102.0	99 1 119.0	113.3 136.0	127.5 153.0	141.7 170.0
16″ × 17″	.01726	200 240	86.3 103.5	103.5 124.2	120.8 144.9	138.0 165.6	155.3 186.4	172.6 207.0

The "constant" is that quantity which being multiplied by the mean effective pressure and the revolutions per minute, the product is the horse-power.

POWER TABLE—CORLISS ENGINES.

Size.		Revolu-tions.	Indicated Horse Power.								Wheel.			Main Bearing		Centre of Shaft to Back Cylinder Head.	Centre of Shaft above Found'n
			80 lbs. Pressure.		100 lbs. Pressure.		125 lbs. Pressure.		140 lbs. Pressure.								
Diam.	Stroke		1-5 Cut-off.	1-4 Cut-off.	1-5 Cut-off.	1-4 Cut-off.	1-5 Cut-off.	1-4 Cut-off.	1-5 Cut-off.	1-4 Cut-off.	Diam.	Face.	Wgth. in Lbs.	Diam.	Lgth.		
12"	30"	90	54	65	69	83	89	102	101	116	9'	15"	5,700	6"	13"	14' 0"	25"
14"	36"	85	83	100	107	128	137	158	126	179	10'	19"	8,900	7"	13"	16' 4"	25"
14"	42"	82	93	112	120	144	154	178	175	201	12'	19"	8,900	7"	13"	18' 7"	25"
16"	36"	82	105	126	135	162	173	200	197	226	12'	21"	10,000	8"	15"	16' 8"	30"
16"	42"	78	116	139	150	179	192	221	218	250	12'	23"	11,800	8"	15"	18' 11"	30"
18"	42"	78	147	176	189	227	244	281	276	317	14'	23"	13,300	9"	15"	19' 1"	30"
18"	48"	75	162	195	208	249	268	308	303	348	15'	25"	15,300	9"	15"	21' 4"	30"
20"	48"	72	192	230	246	296	317	365	360	412	16'	27"	18,700	10"	20"	21' 8"	32"
20"	60"	65	216	260	279	334	358	413	406	466	16'	31"	24,400	10"	20"	26' 2"	32"
22"	48"	72	232	278	298	358	385	443	436	500	16'	33"	23,100	11"	20"	21' 9"	32"
22"	60"	65	262	314	336	404	433	499	490	563	18'	35"	26,300	11"	20"	26' 3"	32"
24"	48"	70	268	322	345	414	444	511	503	577	18'	35"	24,400	12"	22"	22' 2"	34"
24"	60"	65	311	374	401	481	515	594	584	671	20'	40"	28,500	12"	22"	26' 8"	34"
26"	48"	70	315	378	405	486	521	600	590	677	18'	42"	29,000	13"	22"	22' 2"	34"
26"	60"	65	366	439	470	564	602	693	682	784	20'	48"	34,000	13"	22"	26' 8"	34"
28"	48"	68	355	426	457	548	588	677	666	765	20'	44"	31,500	14"	24"	22' 7"	36"
28"	60"	65	424	509	545	654	700	807	794	912	22'	50"	36,000	14"	24"	27' 1"	36"
30"	60"	62	464	557	597	717	770	886	872	1000	24'	52"	38,500	15"	24"	27' 4"	36"
30"	72"	55	494	593	635	762	817	942	925	1062	24'	60"	52,000	15"	24"	32' 0"	38"
32"	60"	62	529	634	680	816	875	1007	990	1137	24'	60"	43,900	16"	28"	27' 8"	38"
32"	72"	55	563	675	723	868	931	1073	1055	1211	24'	66"	58,200	16"	28"	32' 2"	38"
34"	60"	62	597	716	767	920	987	1137	1118	1284	24'	62"	55,000	17"	28"	27' 9"	38"
34"	72"	55	635	762	817	980	1051	1211	1191	1367	24'	74"	59,300	17"	28"	32' 3"	38"
36"	60"	62	669	803	860	1032	1107	1275	1254	1440	24'	70"	55,500	18"	32"	28' 0"	40"
36"	72'	55	711	853	916	1099	1178	1357	1335	1532	26'	72"	75,000	18"	32"	32' 6"	40"
38"	60"	60	722	866	928	1113	1183	1363	1340	1539	26'	....	59,000	19"	32"	28' 1"	40"
40"	60"	62	826	991	1062	1274	1367	1574	1548	1777	24'	....	71,000	20"	36"	28' 6"	42"
40"	72"	55	879	1055	1130	1356	1455	1676	1648	1892	26'	....	85,500	20"	36"	33' 0"	42"
42"	60"	62	910	1092	1171	1405	1507	1736	1707	1960	26'	....	72,000	21"	36"	28' 7"	42"
42"	72"	55	969	1163	1246	1496	1604	1847	1817	2086	26'	....	94,000	21"	36"	33' 1"	42"
44"	60"	62	998	1197	1285	1542	1653	1905	1873	2150	26'	....	79,000	22"	38"	28' 11"	46"
44"	72"	55	1063	1275	1368	1642	1761	2028	1995	2290	30'	....	89.600	22"	38"	33' 5"	46"
46"	60"	62	1092	1310	1405	1686	1807	2082	2048	2351	30'	....	82,500	23"	38"	28' 11"	46"
46"	72"	55	1163	1396	1495	1794	1924	2217	2180	2502	30'	....	95,000	23"	38"	33' 5"	46"
48"	60"	62	1190	1428	1530	1835	1969	2268	2230	2560	30'	....	81,500	24"	42"	29' 6"	48"
48"	72"	55	1266	1520	1628	1954	2096	2414	2375	2726	30'	....	106,600	24"	42"	34' 0"	48"

The deductions to be drawn are that the constants assumed in the tabulated work are substantially correct for an engine of this class of good design and construction and operated under ordinarily favorable conditions. The table of engine efficiencies may therefore be taken as a probably safe guide in the design of such engines, assuming that correct proportion of volume of cylinders and the best ratios of expansion are adopted for the cases to be met.



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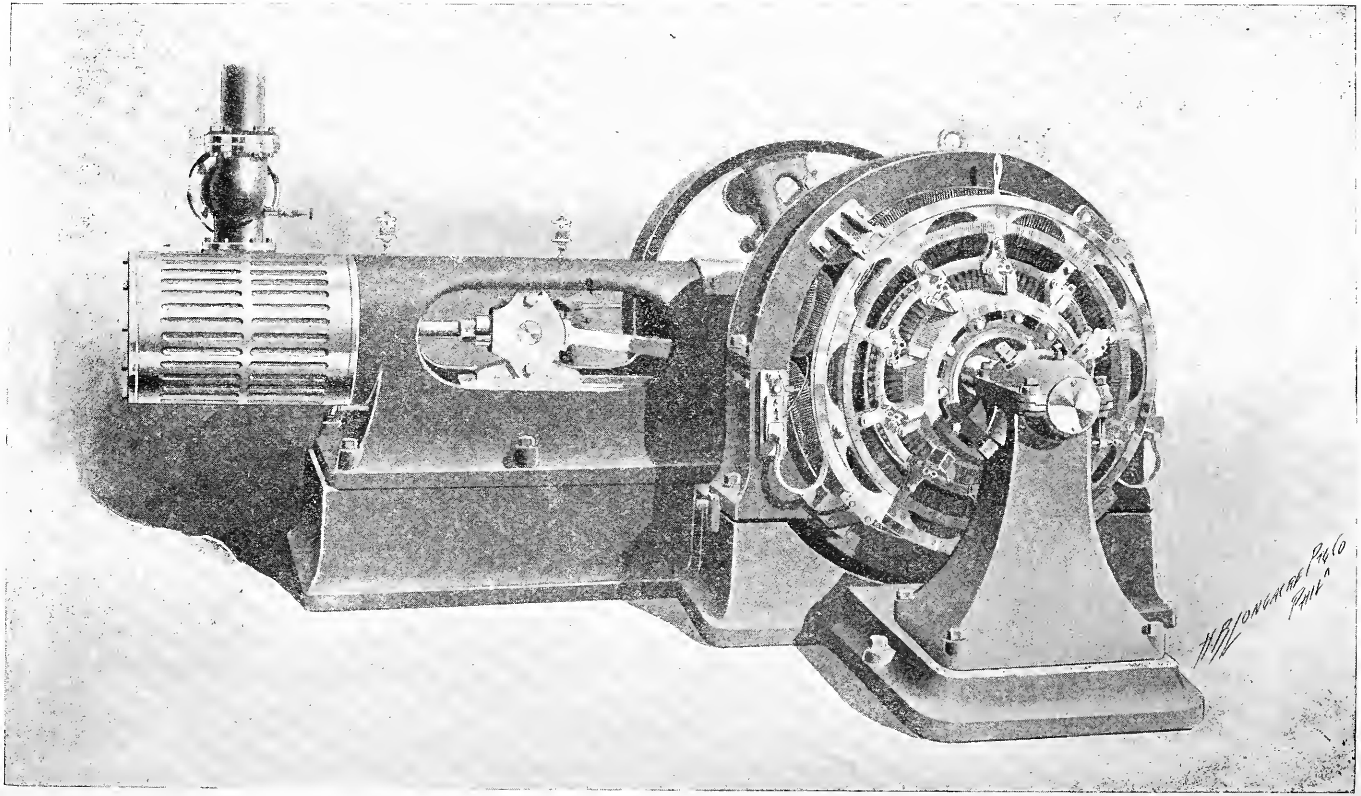


DIRECT-CONNECTED ENGINE.—RYAN AND THOMPSON GENERATOR.

VII.

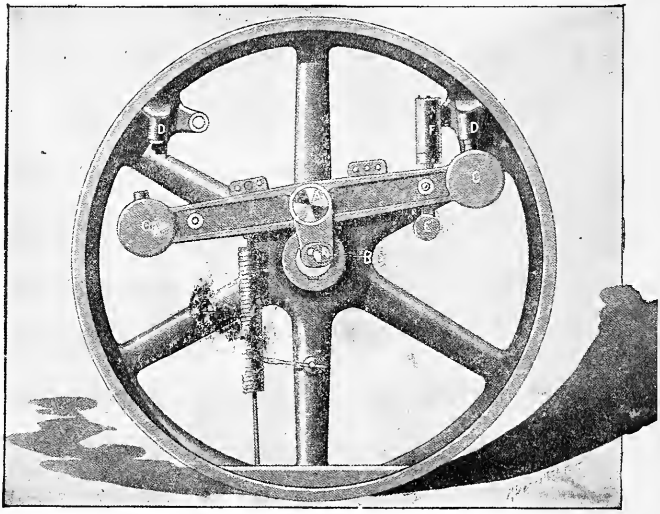
Direct-Connected Engines; Stations.

"DIRECT-CONNECTED ENGINES" have come into use since about 1890 in large numbers. With the older arrangement of belted connection between the engine and the dynamo the space occupied was very large and the cost of wear and tear of belting very considerable. Where land is costly, as in the large cities, and the outlay for real estate therefore necessarily heavy at best, it is important to economize in the occupation of ground- and floor-space; and the abandonment of the belt, the placing of the dynamo directly beside and in actual contact with the driving-engine, is obviously a means of securing immense reduction in the volume and cost of the installation. By the adoption of the multipolar generator it becomes practicable to secure any desired speed of rotation, and to adapt the speed of engine and of dynamo, the one to the other, in the most satisfactory manner. The cost of the generator is somewhat increased for a given power; but since, for a stated output, the quantity of metal employed is not variable to any large degree, the difference in this respect, especially for large powers, is not enough to influence the solution of the question in any important degree.

Steam-engines employed for this system of application of power are sometimes horizontal, oftener vertical in large powers, and may be of any type found useful for any pur-

poses, from the simple upright "semi-portable" style of engine to the triple- and quadruple- expansion marine type, which latter is a favorite with a number of designers and engineers. The following are illustrations of such applications of the moderate-speed and the high-speed engines.

As an excellent illustration of the direct-connected engine the accompanying plate is given—a McEwen engine with the generator of Professor Ryan, head of the Department of Electrical Engineering of Sibley College, who was



"INERTIA GOVERNOR."

one of the early designers of this type. The engine is built either horizontal or direct, like other forms shown elsewhere. The generator has from 10 to 20 poles, as speeds of engine vary from 500 down to 150 revolutions and power demanded

increases from, ordinarily, 10 or 15 to 300 or 400 K. W., 400 or 500 H. P.

The engine has the same general form as the high-speed engine of the best makers usually, with well-studied details and an interesting type of governor, very simple, very effective, and very reliable. The action of centrifugal force and that of inertia conspire to insure quick, strong, and accurate movement, while the dash-pot, *F*, prevents swinging. A pivoted and weighted bar, *CC*, a spring, *G*, and the dash-pot constitute the whole system. The bearing and its pin are fitted with steel rollers and no lubrication is needed.

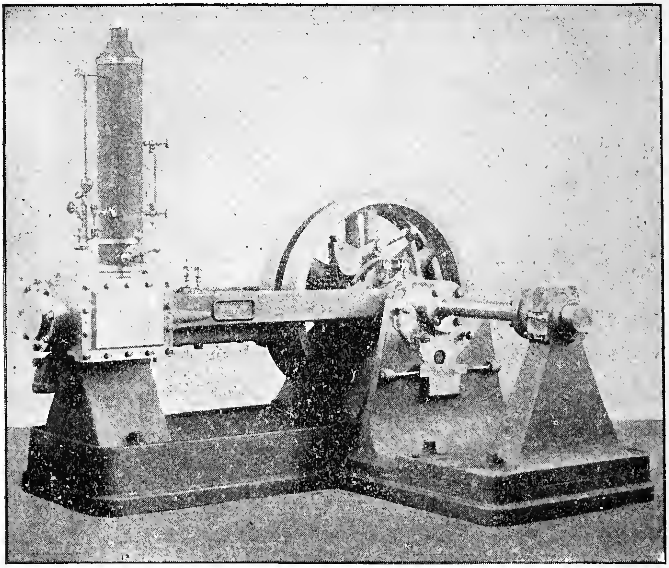
The generator here shown is built with Ryan "balancing coils" and various details by Mr. Thompson all resulting in giving a machine weighing in the sizes just specified from about 60 to 80 pounds per K. W., 45 to 60 pounds per H. P., and permitting variation of work through wide ranges without arcing or other difficulty.[1]

The cut on page 270 shows a STRAIGHT-LINE ENGINE connected to a General Electric Company's dynamo. Aside from the adjustable outboard pedestal, the base, pedestals, and dynamo-supports are cast in one piece, where it can be placed if in one piece, and the whole arranged to be filled with masonry before setting on foundation.

The arrangement for connection between engine and dynamo includes a safety-coupling between the two. A flange is forged on the dynamo-shaft, a cone is keyed and pinned on the engine-shaft, and a solid bush is bolted to the flange and drawn on the cone so as to create driving-friction

1. For details of this interesting construction see the papers of Prof. H. J. Ryan and of M. P. Thompson.

enough to run the dynamo, but not so much as to burn it out in case of a short circuit. Either dynamo or engine can be dismantled without disturbing the other.



DIRECT-CONNECTED STRAIGHT-LINE ENGINE.

Direct-connected engines are often of great size. Thus the West End Street Railway Company of Boston have two Rice & Sargent cross-compound engines, direct-connected to electric generators, of which the general dimensions are as follows:

CROSS-COMPOUND DIRECT-CONNECTED ENGINES.

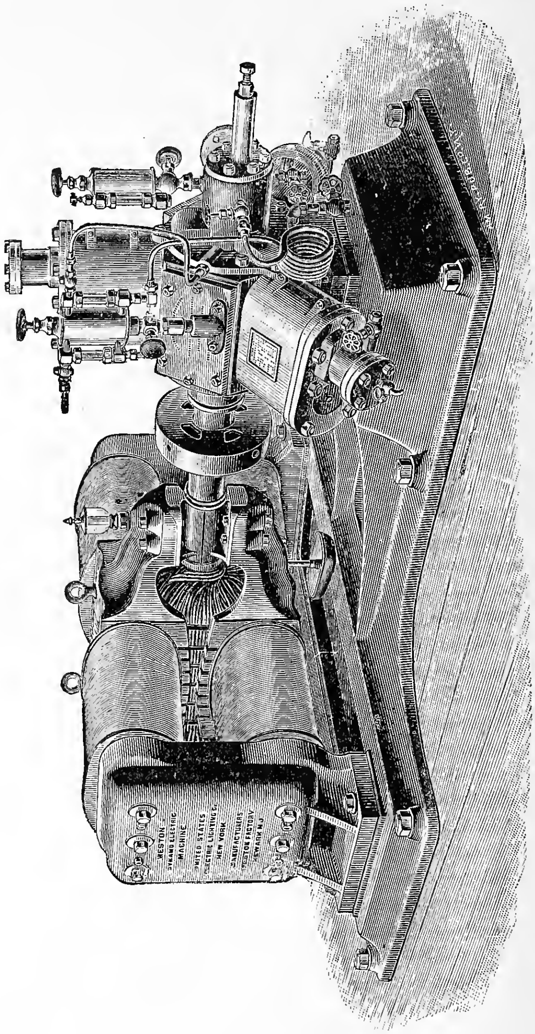
Indicated horse-power, each engine	1,500
Diameter of high-pressure cylinders	26 in.
Diameter of low-pressure cylinders	50 in.

Length of stroke	60 in.
Number of revolutions per minute	80
Steam-pressure per square inch	150 lbs.
Diameter of fly-wheels	24 ft.
Weight of each fly-wheel	120,000 lbs.
Diameter of shafts in wheels	24 in.
Diameter and length of main bearings	22 in. × 38 in.

The rims of the fly-wheels are composed of forged steel. Jet-condensers and air-pumps, driven by independent engines, are used. Reheating receivers are placed between the cylinders, and the piping is arranged so that either cylinder of either engine may be run alone if desired.

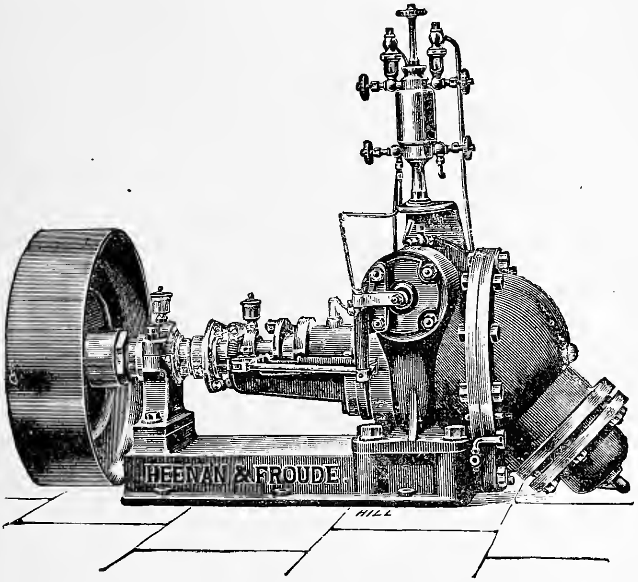
The Brotherhood type of engine, characterized by its equidistant cylinders—three or four—arranged to connect with a common crank and pin, is an example of complete balancing, and can be driven, like all such engines, up to enormously high speeds. The author has known them to be carried, experimentally, up to above 2,500 revolutions per minute, and 1,000 revolutions has been frequently attained. The construction here illustrated is that built in the United States by the Chester Co. This form of engine is illustrated in the figure as applied to a standard type of dynamo-electric machine. With most forms of even "high-speed" engine a low-speed dynamo must be especially designed to couple with it; but this class of engine adapts itself to the ordinary speeds of moderate-sized and large dynamos.

Tower's Spherical Engine, as constructed by Heenan & Froude of Manchester, G. B., is shown in the engraving—a peculiar and very compact and fast-running machine, especially applied to the driving of electrical and other rapidly rotating apparatus. It consists of a spherical work-



Three Cylinder Engine

ing "cylinder" in which a disk spins, driving its supporting shaft at any required speed. These engines are coupled direct to the dynamo, or to a fan or pump, and are much



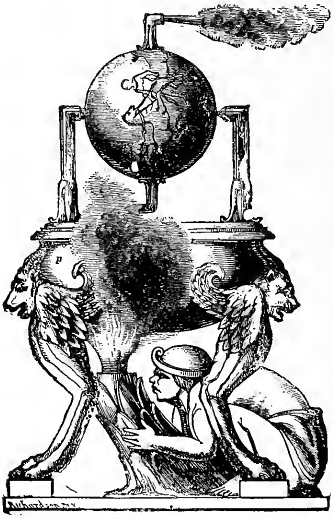
THE TOWER SPHERICAL ENGINE.

used on shipboard when compactness and noiselessness are demanded. This is one of the most singular forms of steam-engine yet successfully introduced.

THE STEAM-TURBINE constitutes a class of steam-engine which, although the first invented, and familiar as a type to all engineers from the days of Hero the Younger, and known to have a high theoretical and moderately high actual efficiency, has been only experimentally used until a very recent date. That of Hero is illustrated in the next figure.

The Atwater engine of about 1840 was of this type, and was said to be as economical as the engines of the time of equal power. Steam-turbines of the inward-flow type have been used by Gorman and others.[1]

The later "compound" steam-turbine has recently been



HERO'S STEAM TURBINE.

somewhat extensively employed in the operation of dynamo-electric machinery. It consists of two sets of parallel-flow turbines set, in twin series, on one shaft on either side the induction-pipe, thus balancing. The passages are gradually enlarged as the volume of the steam increases with its progressive expansion.

The turbines thus alternate with their guide-blades, and

1. Rankine, p. 538.

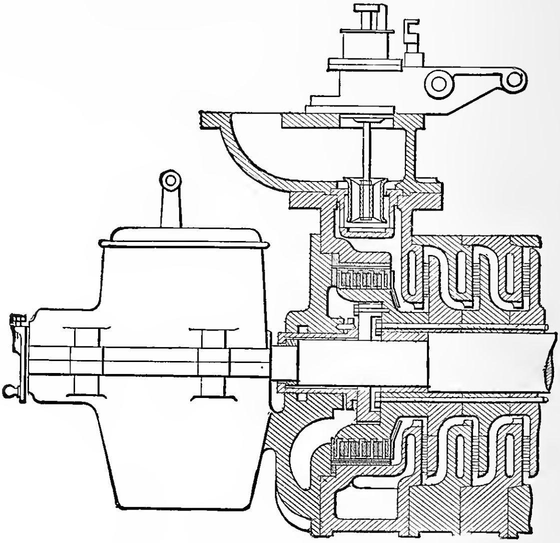
both the vanes and the blades are carefully proportioned and set to secure maximum attainable efficiency at the proposed speed of rotation, their pitches and depths being suitably varied.

The computed efficiency, without allowances for wastes, is about 87 per cent. The actual consumption of steam is found to be 35 to 40 pounds per electrical horse-power produced and per hour as steam-pressures rise from 60 to 90 pounds by gauge. The speed of rotation ranges from 5,000 or 10,000 revolutions per minute upward, according to size and steam-pressure, 18,000 and 20,000 being common speeds for the smaller sizes.

Dow's turbine is an inward-flow wheel with concentric sets of guides and vanes in series, and is said to have attained 35,000 revolutions per minute, working regularly at 25,000, consuming 55 pounds of steam per horse-power per hour. Only the most perfect construction is here admissible.

The theory of this type of machine is that familiar to the hydraulic engineer, and the speeds of orifice for maximum efficiency are well-known to be infinite in the Hero class of turbine and approximately one-half the final velocity of flow in the guide-blade turbine. Since these speeds are impracticable in their use, a certain loss of energy is thus inevitable. In compensation for this loss, in the steam-turbine, is the fact that it is not subject to that fluctuation of temperature of parts exposed to contact with the steam which results in large wastes by cylinder-condensation in the common forms of steam-engine. In this way a gain of from 25 to 50 per cent, as compared with the latter, is to be counted upon.

The Dow turbine, as built for work in connection with the Howell torpedo, gives an average of about 11 horse-power in coming up to speed in regular working, at 60 pounds steam-pressure, and weighs from 100 to 150 pounds, or not far from 13 pounds per horse-power.[1] Its fly-wheel



A SECTIONAL VIEW OF THE PARSONS TURBINE.

rim attains a speed of nearly 7 miles an hour at 10,000 revolutions per minute. The designer estimates its power at 150 pounds steam-pressure and the same speed at 40 horse-power, or one horse-power to 3.75 pounds weight, and states that this may be still further reduced to the extraordinary minimum of $2\frac{1}{2}$ pounds weight per horse-power, a

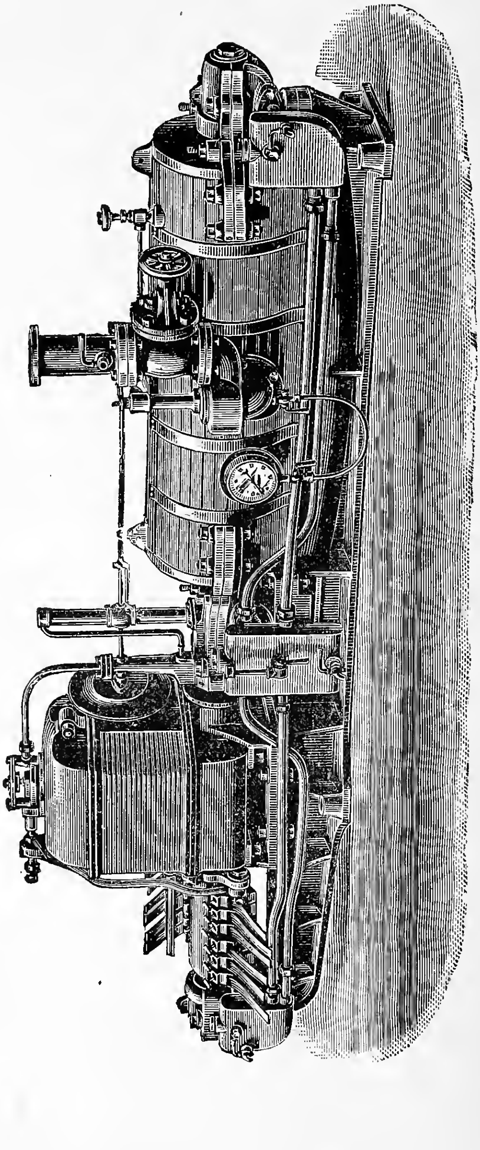
1. Electrical World, April 18, 1891.

figure well within the estimated allowable maximum for use in aeronautic work.

The steam-turbine of Parsons is an engine consisting of a series of turbines, the different pairs of guides and wheels being so placed that the fluid passes successively from one pair to the next. Of the two forms, radial and axial flow, only the latter have been used here. Two series of cylindrical turbines are used, arranged symmetrically to the right and left of the central steam-inlet, the exhaust taking place from the two ends. In this manner a balance is obtained, and the bearings are relieved of end-pressure. Oil is forced through the bearings by a pump. The bearings are thus forcibly deluged with oil, which returns to a reservoir. The governor is a suction-fan mounted upon the spindle and connected with a diaphragm, which operates the throttle-valve against the power of a spring. Its action is found to be rapid and certain.

Such engines have been successfully employed in driving electric machinery and in "spinning" the "fly" of the Howell torpedo. For alternating electric currents this system possesses the peculiar advantage of permitting a "dynamo" to be employed having but two poles. It may be readily driven continuously at speeds exceeding 10,000 revolutions per minute, and, like the Dow turbine, elsewhere referred to, has been driven at 20,000 and upward. With the lower speeds of revolution usual with ordinary engines the number of poles required generally approximates the quotient 12,000 divided by the speed of engine, if directly connected.

The best of these machines have demanded from 35



PARSONS' STEAM-TURBINE.

pounds of steam per horse-power per hour upward, according to pressure employed. It may be assumed that they will require not far from the weight

$$W = \frac{a}{\sqrt{p_1}},$$

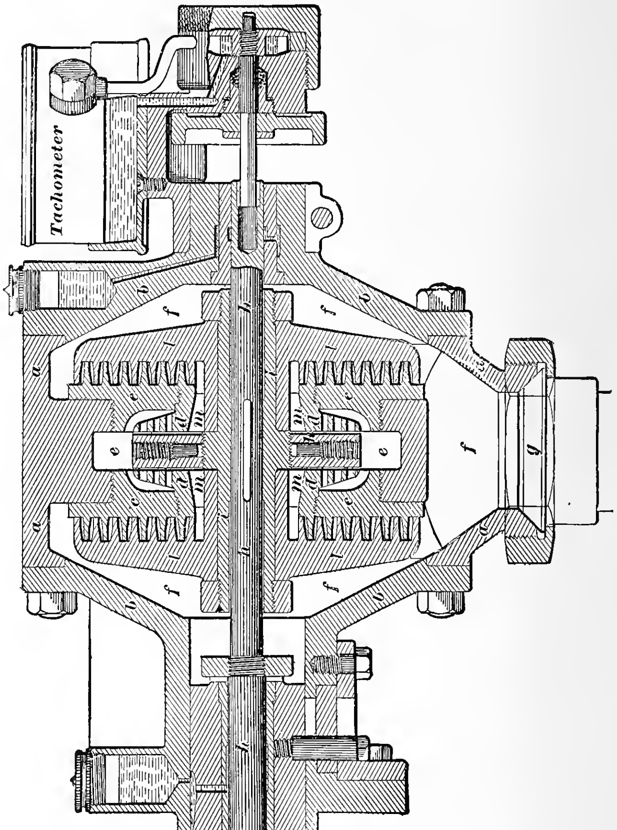
where p_1 lies between 50 and 200 pounds per square inch by gauge and the apparatus is operated under favorable conditions, the value of a lying between 350 and 400 with dry steam.

In the United States the substitution of the Dow turbine for the systems previously in use, for torpedoes, has brought down the weight and volume of machinery from the earlier minimum of 360 pounds and three cubic feet per machine to 75 pounds and one cubic foot.

In this turbine the steam enters through the passage *ee* and finds exit through *fff* to the exhaust-pipe *g* (page 280). The main shaft, *hh*, is carried on journals at each side the casing, as seen, and a sleeve, *ii*, stiffens the central part of the shaft and carries the turbine-wheels proper, *ll*, of which a pair are used to insure a longitudinal balance of pressures. These are "inward-flow" turbines, "compounded" by having a number of concentric circles of blades working in series, in conjunction with the guide-blades, on *cc*, as is well shown in the next figure.

Steam entering from *ee* must pass through the balance-disk, *k*, on the shaft, the spaces on either side and the passages *mm* to reach the turbine-disk. This keeps the sleeve and the three disks automatically adjusted longitudinally at the intended very minute distance from the guide-disks,

and insures that contact shall not take place. The sleeve is splined to the shaft, and permits slight endwise motion

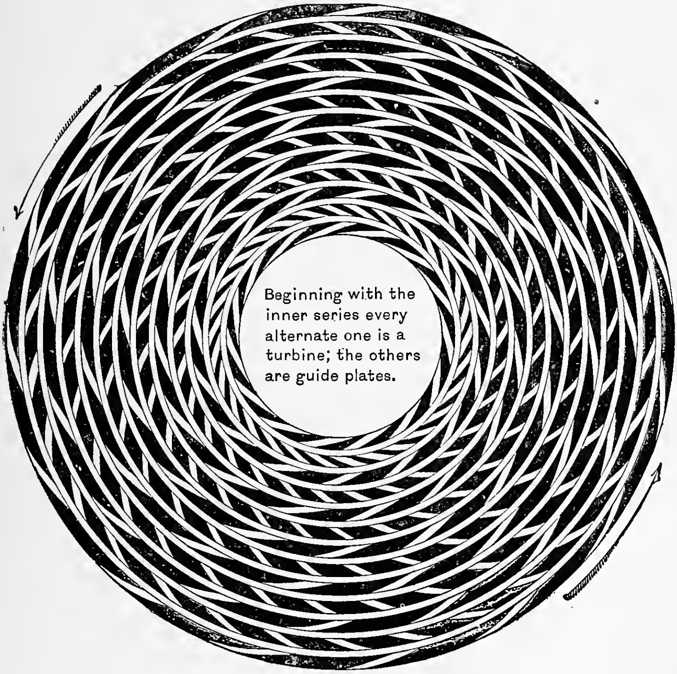


DOW STEAM-TURBINE.

of the latter without affecting the action of the turbine.

The latest development of the steam-turbine in modern

work is a modification of the machine of Branca of 1629, of which an illustration is given, page 282, as drawn by the

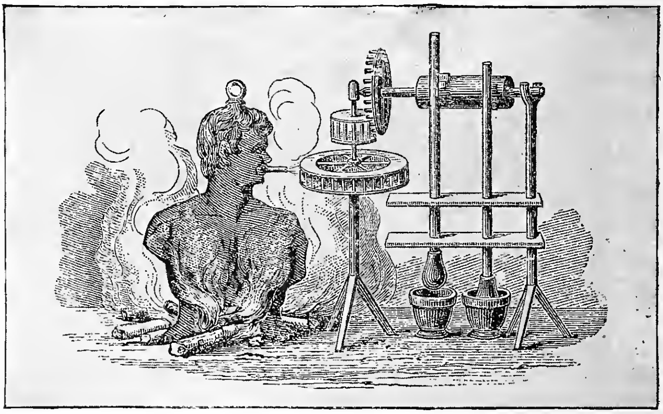


Dow Turbine.

inventor.[1] The turbine of De Laval is constructed on the same principle as is, among the water-wheels, that of Pelton. In this form of steam-turbine the steam is expanded from the boiler-pressure to that of the atmosphere or, in the case of a condensing engine, to that of the condenser, and its potential energy thus converted into the

1. History of the Steam-engine, by R. H. Thurston, Fig. 6; N. Y., D. Appleton & Co.

kinetic form and with as complete utilization of all stored energy, whether that of sensible or of latent heat, as the thermodynamic action of the case permits. The issuing jet of steam then impinges upon the buckets of the rapidly revolving turbine and is thus reversed in direction of flow,

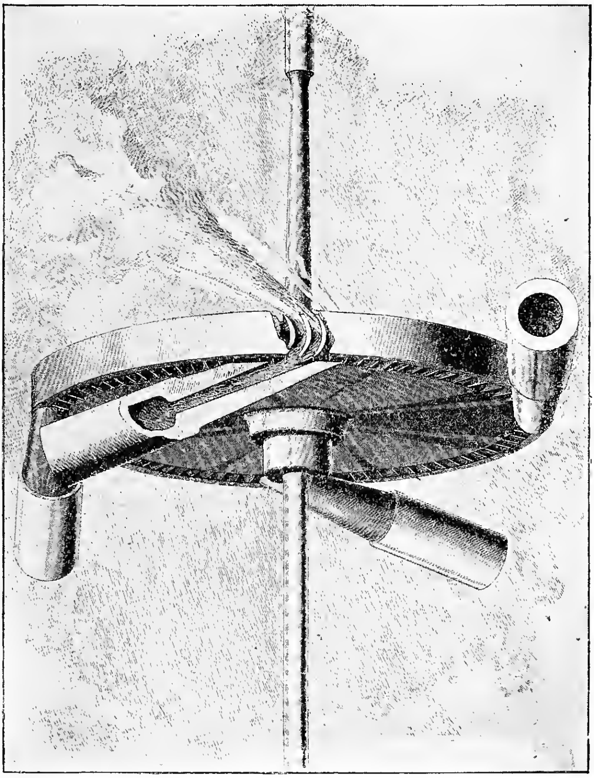


BARCA'S STEAM-ENGINE A.D. 1629.

and would be completely deprived of its energy by transfer to the machinery were it practicable to drive it up to the needed velocity of rotation; but friction and insufficient speed of rotation together waste much of the power stored in the outflowing vapor.

The arrangement of the apparatus is clearly shown in the illustration on page 283, and is seen to be precisely that of the machine of Branca, with modern refinements in design and construction. It is, however, notwithstanding the defects of essentially high velocity of rotation and of loss by friction and by deflection of the jet of steam from its

proper path, a very remarkably efficient and economical form of the steam-engine. Its velocity is from 15,000 to 25,000 revolutions per minute, according to size and power, and this means, of course, its application principally to the



De Laval's Steam-Turbine.

propulsion of exceptionally high speed machinery, mainly to the driving of electric generators, which also must be specially designed for its use as a motor. The gearing

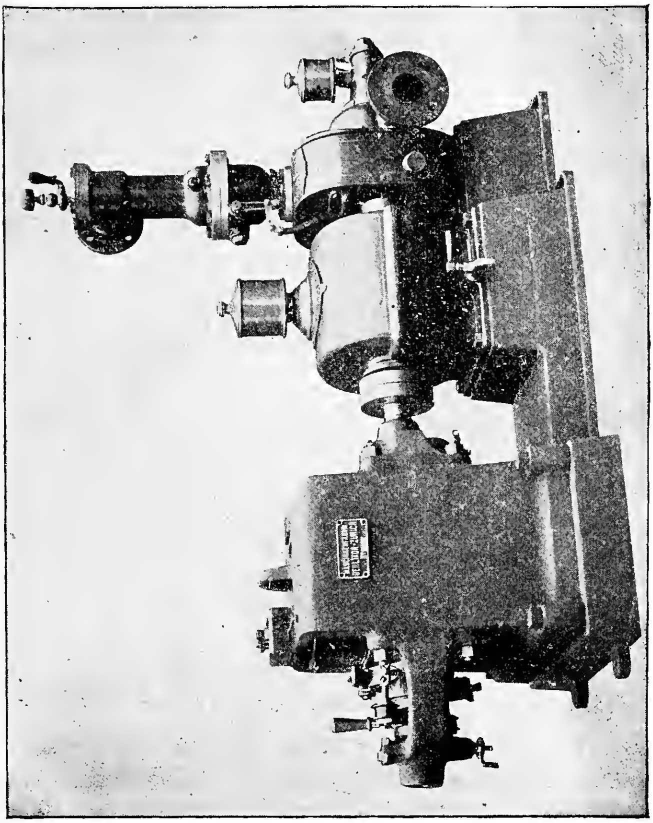
down of the steam-turbine often presents as troublesome a problem as the formerly practised gearing up of the older and slow-moving forms of steam-engine.

The machine is usually geared down from its enormously high speed to one-tenth as high velocity at the generator-shaft by means of beautifully made helical gearing, and the almost impossible task of securing smooth running by balancing the rapidly revolving disk of the turbine is evaded, more or less perfectly, in the machines built by this inventor by the adoption of a long and flexible spindle instead of a short and rigid shaft, thus permitting the disk to take its own position and to revolve about its natural center of revolution.

Many of these machines have now been installed, particularly in Europe, and the reported results of their trials have been often very favorable. In some cases their use for large "plants" has been adopted, and individual turbines have been constructed of above 300 horse-power.

Both forms of turbine have been reported to give a "water-rate" of less than 20 pounds per horse-power per hour. The Parsons turbine, tested by Professor Ewing, furnished 100 Board-of-Trade units of energy at a cost of 20 pounds of steam per horse-power per hour, equivalent, as estimated, to about 15 pounds per I. H. P. with the standard form of engine, and fully equal to the best average work of the latter class of engine under similar conditions of operation. At half-load the water-rate rose to figures one-half higher. A De Laval turbine was reported, by its exhibitors at the International Exhibition, 1893, to have been tested at the University of Stockholm that season, and to have shown a

water-rate of 8.95 kilogs., 19.7 pounds, per horse-power per hour when delivering 63.7 horse-power on the brake. In the Parsons wheel the pressure was at entrance 100 pounds per square inch, and in the Laval wheel 108 to 122.



DE LAVAL STEAM-TURBINE DYNAMO.

The Ewing trial was conducted with slightly super-heated steam, the Laval trial with saturated. In the latter case

the vacuum was 27 inches, in the former somewhat less. Turbines of the Branca class, built under the patents of De Laval by Breguet of Paris, were supplied to the Edison Illuminating Co. of New York with the following guarantee :

"Each 300-horse-power turbine is to drive two Desroziers dynamos, each of 100 kilowatts (133 horse-power) capacity. The turbine-shaft is to run at 13,000 revolutions, driving at a speed of 1,300 revolutions, by means of helical gearing, two dynamo-shafts situated on either side of the turbine-shaft. . . . If the turbines are built to be operated either condensing or non-condensing, as a mongrel type, with a steam-pressure of 10 kilos per square centimeter (142 pounds per square inch) at the throttle, and with a vacuum of 65 centimeters at the condenser, the steam-consumption per brake-horse-power is guaranteed not to exceed 8½ kilos (18.7 pounds) ; with a free exhaust the steam-consumption is not to exceed 16 kilos (35.2 pounds).

"If it should be contemplated to operate the turbines ordinarily with a condenser, the guaranteed steam-consumption will be reduced to 7½ kilos (16.5 pounds) per brake horse-power. In this case the turbine-disk would have a diameter of 0.75 meter (29 inches), instead of 0.50 meter (19⅝ inches) for the mongrel type."

LIGHT- AND POWER-STATIONS have come to be the most numerous and extensive of all sources of mechanical energy derived by thermodynamic transformation from the heat-energy of steam and of fuel. Hundreds of millions of dollars have been invested in the United States alone in electrical transmission of energy from economically located and

arranged steam-engine and boiler "plants." Some establishments for power-production are situated in the midst of great cities and supply the surrounding districts with electric lights ; others furnish the power for operation of hundreds of miles of electric railways ; still others, placed where the sum total of their costs of operation and maintenance shall be, as nearly as can be reckoned, a minimum, between cities or on lines connecting cities with suburban villages, give out energy in always sufficient quantity to meet the enormously varying demands of lighting or of power lines, or both combined ; still others, again, are placed at the great waterfalls of the country and, substituting the water-wheel for the steam-engine, gather up the floating energy of the flowing stream and convert it into electrical form for transmission five, ten, twenty, a hundred miles, to the point at which it is called for, to be employed, untransformed, in lighting, or transmuted into mechanical energy to drive motors and machinery of all kinds.[1]

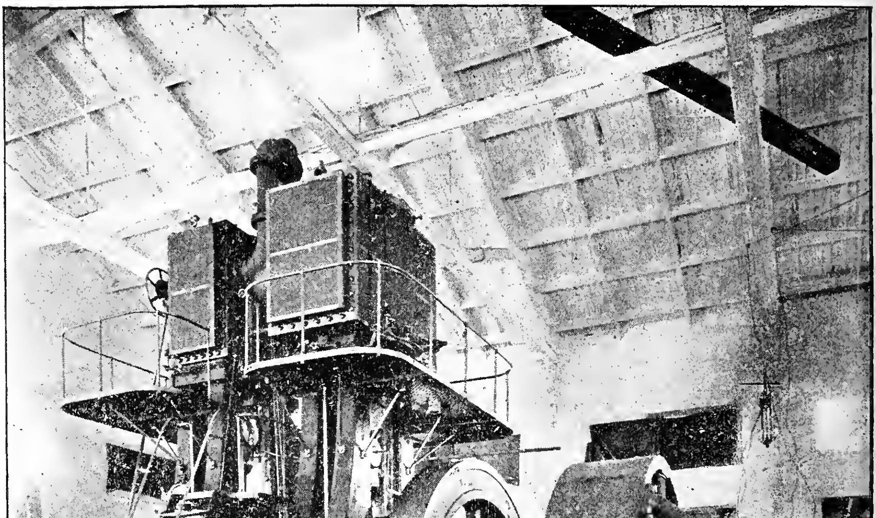
THE DEVELOPMENT of electric systems of distribution of power and light commenced about 1875 with the operations of Farmer, of Brush, and of Thomson and Houston. In the earlier days the "units" adopted were small, and the generators were rarely above 150 kilowatts capacity. All the work was performed by means of the then only familiar type of machine ; the bipolar generator, and the alternating current, with its wonderful possibilities, were unappreciated by the most prominent builders and electricians. The latter

1. In the following discussion we have drawn upon the published papers of Mr. C. J. Field most freely, and on lectures delivered before Sibley College at Cornell University. We are under obligations to the courtesy of the publishers and editors of Cassier's Magazine for the illustrations included in this part of the discussion.

field was only opened in a practical manner ten years later. No experience and little knowledge guided the engineers of the time in their designs of machinery or in the arrangement of their stations. The results on the economy of current-supply and utilization of the extreme irregularity of demand for power and for light were understood by few, and even fewer saw what was the direction of needed improvement with a view to meeting such unprecedentedly exacting requirements. Large losses followed the endeavor to introduce the new system of transmission of energy, and enormous sums were invested only to give disappointment in the magnitude of returns, if not by absolute and serious or entire loss. About 1890 the true methods of design and of construction and operation became recognized by many of the better class of designers and constructors, and from that date steady advance has characterized this field of engineering in all its departments.

One of the most striking gains has been seen in the improvement of the steam-engine for electric-light and -power production. It has been given a marvellous accuracy in regulation, a fairly high efficiency and moderate cost in construction and operation. With a single valve the so-called "automatic" engine is found economical under average conditions, and when of good design up to what were once thought high powers—250 to 350 horse-power. The engine with detachable valve-gear, as that of Corliss or of Greene, has been hardly less improved, and affords good regulation, as well as retains its exceptional standing in its economy of fuel. It has even been brought up to speeds of revolution exceeding 100 per minute, and has been built in forms espe-

[*To face page* 289.]



MODERN DIRECT-CONNECTED 1,250 H. P. UNIT.

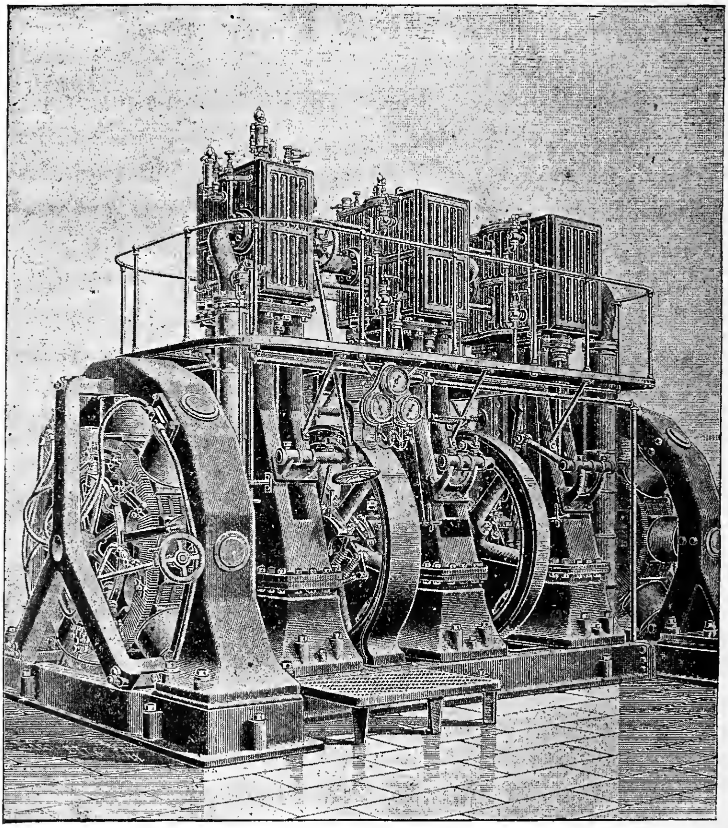
cially adapted to the peculiar work here demanded of it. The latest forms illustrate the compactness of the merchant-marine type, and these vertical engines are finding place wherever land is costly or where, for other reasons, restricted floor-area is desirable.

The steam-boiler is now usually of the water-tube type, both because of its safety from danger of explosion and its peculiar compactness. Numerous automatic accessories, as "mechanical stokers," automatic feed-apparatus, and systems of carriage of coal and ashes, and even automatic weighing-machines, have come into use in large stations.

The generators in extensive plants have been made of previously unimagined sizes and powers; 1,000, 2,500, and even 5,000 horse-power dynamo-electric machines being demanded and used by engineers proportioning plants for the largest distributions and supplied by builders. These machines are now nearly all of the multipolar types and generally direct-connected. In railway work it is common to connect one engine to one dynamo, while in lighting it is quite as usual to drive two generators, one from either end of the shaft of one engine.

Alternating machines are now employed in as large powers and for even more extensive transmissions, and are made for any amount of current up to above 3,000 kilowatt rating, and for any desired method of connection or of distribution of current. They are made single-phase or multiphase, as needed, and have found their way into use with extraordinary rapidity, especially for very long distance transmissions. In fact to-day any kind of service may be had from any standard form of machine.

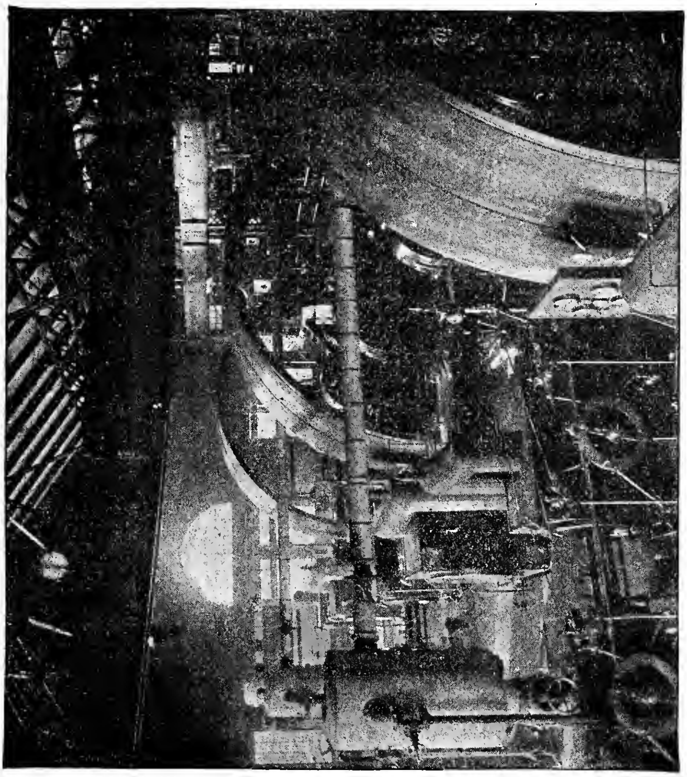
Storage-batteries are now in use in many places to reduce the irregularity of demand and of supply of electric cur-



TRIPLE-EXPANSION ENGINE AND DIRECT-CONNECTED GENERATORS.

rent; thus, by permitting the steady working of the generating system, giving opportunity to employ economical proportions of driving-engines. The tendency of change has

also led in the direction of, as far as practicable, concentrating the machinery, in order that we may avail ourselves of the economical advantage of production in large quantity

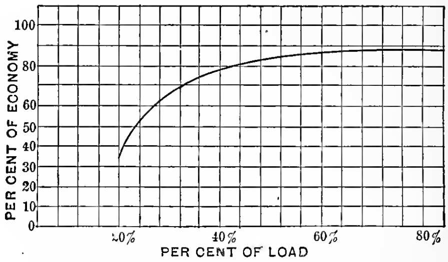


POWER-HOUSE, WEST END RAILWAY CO., BOSTON.

by a single collection of machinery and with a single crew of workmen and office employees. The art of distribution of stations, where their separation is wise, is well understood, and maximum economy of power- and light-production has come to be very generally attained.

In recording cost the kilowatt-hour is now usually taken as the unit against which it is measured, and this, the equivalent of about one and one-third electrical horse-power, thus becomes the gauge of the energy received from a stated amount of mechanical power expended. On the subject of costs Mr. Field remarks : [1]

"The economy of the steam-engine as the generating unit driving the electrical generator is one of the main fac-



E. H. P. Output per Unit Total H. P.

tors in the cost in connection with the economy of power-station work. The economy of these units, as we stated, has been largely improved ; the size of the units has been increased, and to-day stations are built with large units, adapted for variations of load for which the station is used. There is still in many cases, and in fact almost generally, a considerable variationi n the economy during the 24 hours, with the variations which hold in commercial practice, both in railway and lighting work.

"I do not know that we can better illustrate how this variation affects the pounds of coal per kilowatt than to

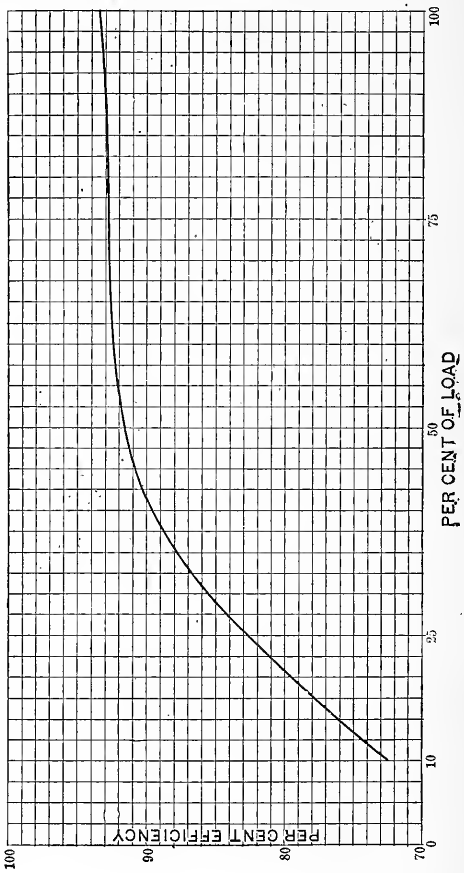
1. Cassier's Magazine, 1896, p. 428.

instance an example which has come under my observation in a power-station which is showing one of the best results that I know of. The variation in coal consumed per kilowatt during 24 hours is about as follows: From 9 A.M. to 9 P.M., $4\frac{1}{4}$ to $5\frac{1}{2}$ pounds of coal per K. W. hour generated, charging everything up to the generation that should be charged. For the balance of the 24 hours the results run from $5\frac{1}{2}$ to $9\frac{3}{4}$ pounds of coal. These figures are startling, but they are facts.

"We further illustrate this by showing the combined efficiency of the generator and engine unit as a whole in the figure, showing, at 20 per cent load, an output efficiency of about 35 per cent of the ratio between electrical H. P. output and total indicated H. P. of the engine; at about 50 per cent of the load the efficiency has increased to 80 per cent; at 65 to 70 per cent of the load it is up between 85 and 87 per cent, and the total efficiency is between 85 and 90 per cent. The figures show that units should not be operated at less than 50 per cent of the capacity, and preferably at from 65 or 70 per cent.

"The efficiency-curve of the generator shows that the generator holds a higher average efficiency than the engine when we compare it with the combined efficiency of the engine and generator. This shows at 10 per cent of load an efficiency of over 70 per cent; at 25 per cent of load an efficiency of 82 per cent; at 50 per cent of load an efficiency of $91\frac{1}{2}$ per cent; at 75 per cent of load an efficiency of 93 per cent; and full load efficiency of between 93 and 94 per cent. Test records show, in the best power-stations, that with an efficiency of, say, three pounds of

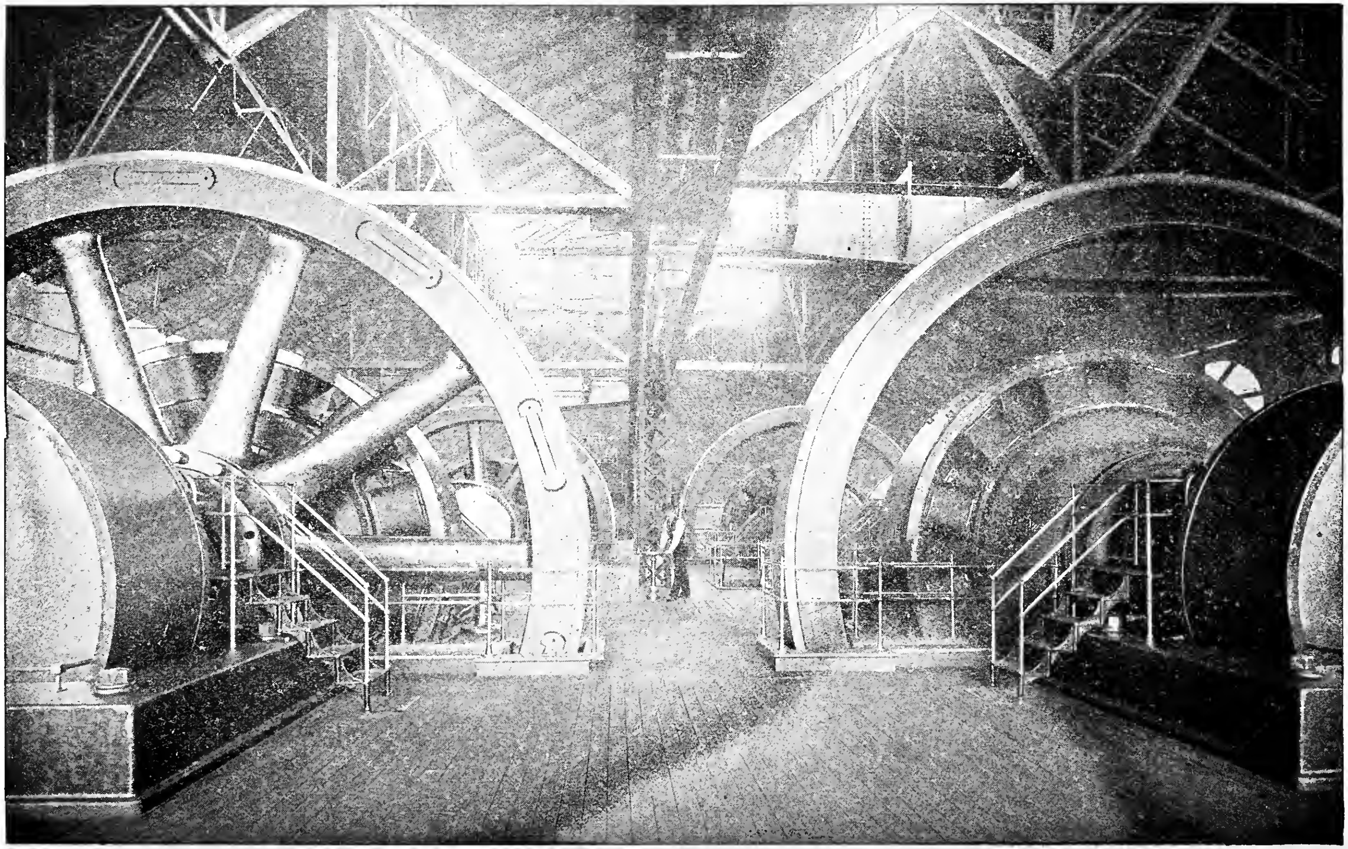
coal per K. W.-hour produced, for a unit operating at normal load, the station record, charging everything against the



EFFICIENCY OF GENERATORS UNDER LOAD.

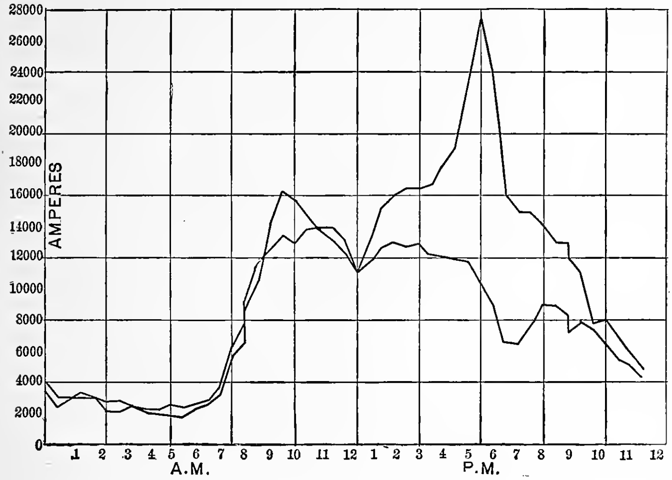
coal-consumption for the 24 hours and taking the average loads under the best of conditions, would be about $4\frac{1}{4}$ pounds of coal per kilowatt for a week's record.

[To face page 295.]



POWER-STATION, CITY RAILWAY CO., BROOKLYN.

"These 3 pounds of coal per K.W.-hour, transferred into pounds of water per H. P. generated, would be equivalent to about 15 pounds. It should not be understood that



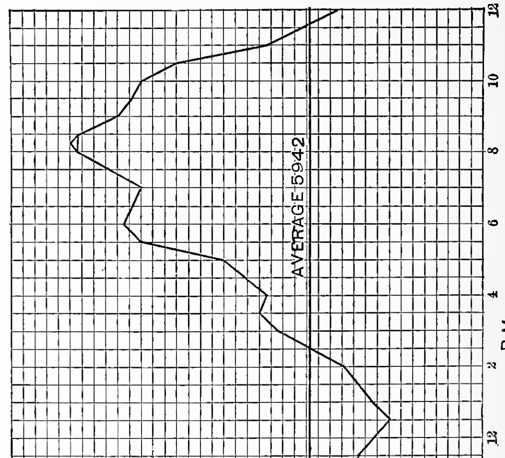
LOAD-DIAGRAMS, CENTRAL STATION.

the engine will show this continually throughout the 24 hours, but under normal and constant load only, under the best conditions.

"I have tried to illustrate by some load diagrams an idea of the variations of load during different parts of the day for central-station lighting and railway work. The figure shows two load days in a large central station, the one with the more average load being a dark, stormy day in the summer-time, and the other being a December day, showing maximum load conditions between nine and ten o'clock in the morning and between five and six o'clock in the afternoon.

"The next figure shows an example of a day in another

station, and on it is given also the average load, which shows the following results: Maximum load, 14,000 am-



LIGHTS IN ARC AND INCANDESCENT CIRCUITS, REDUCED TO EQUIVALENT 16 CANDLE-POWER = 90,000 LAMPS.

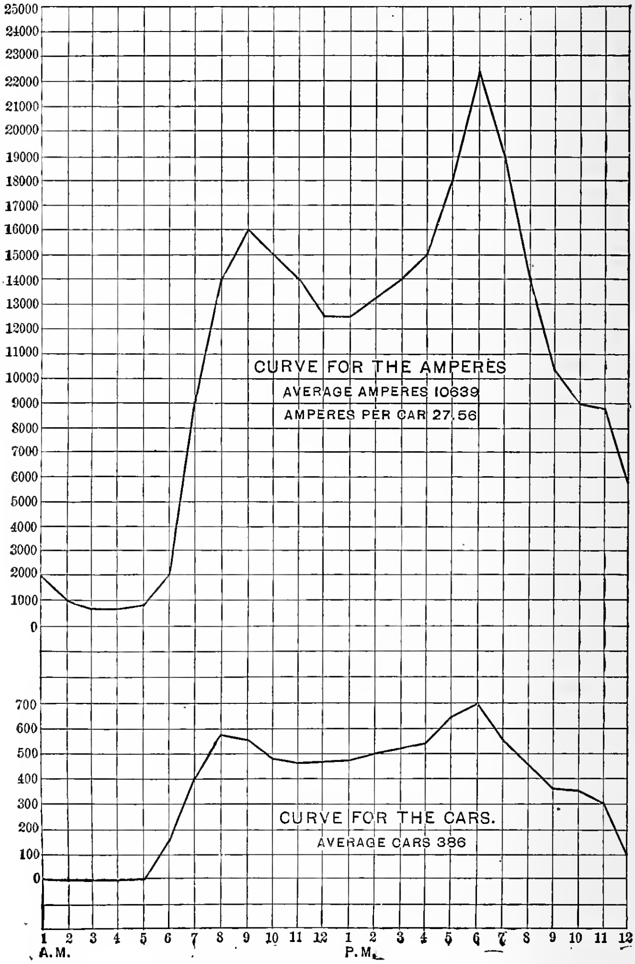
Maximum load, approximately, 14,000 ampères = 28,000 16 c. p. lamps = 31 per cent of connections.
Average load, approximately, 5,942 ampères = 11,884 16 c. p. lamps = 13 per cent of connections.

pères; average load for the day, 5,942; total number of lights connected to station, both arc and incandescent,

reduced to equivalent in 16 candle-power lamps, 90,000. The maximum load of 14,000 ampères is equivalent to, approximately, 28,000 sixteen candle-power lights, or about 31 per cent of those connected. The average load shows about 12,000 lights of 16 candle-power or an average of about 13 per cent of the connections. This gives a good relative idea of the average and maximum loads in a large station, and their ratio to the number of lights connected to the station, showing that the generating capacity is not required to be more than from 30 to 35 per cent of the total number of lamps connected, exclusive of reserve.

"These diagrams also illustrate and show the need and requirements of averaging up the load during certain hours, by increasing the motor load during the light hours and offering special inducements to light and other customers for increased load during those hours. Electric companies have found that they can furnish motor-power for a lower price per K. W. than lighting power, because it comes, as a rule, during a part of the day when the load is light.

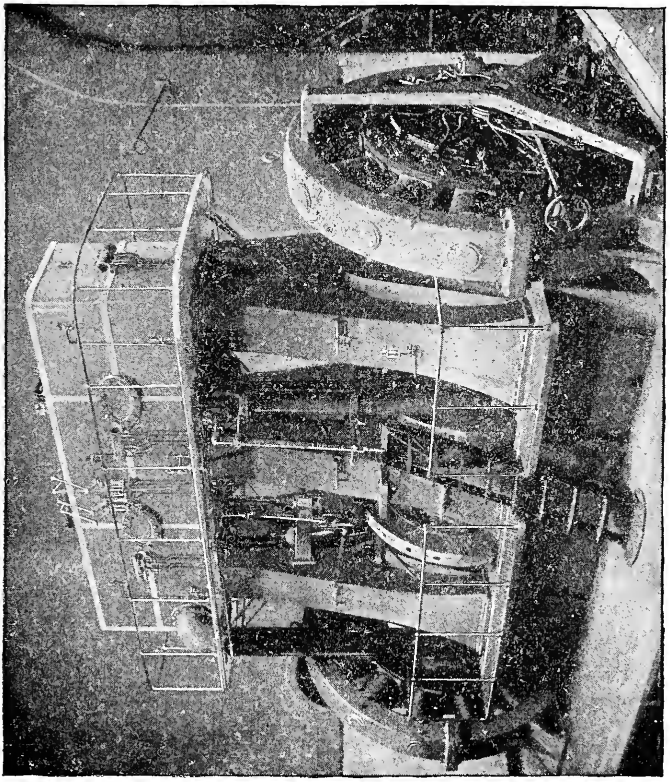
"To illustrate a railway power curve is a difficult matter. The variations of a railway curve are often from maximum to minimum within a few moments. In a large station, with a large number of cars running, the load takes a more average condition and approximates more generally to the curves of prominent lighting-stations, showing maximum points of load during the morning and evening rush hours when people are going to or returning from business. The last set of curves illustrates the general average fluctuations of load, without indicating the momentary fluctuations. It



LOAD-DIA RAMS, RA LWAY-STATION.

gives also a load diagram showing the average changes for the number of cars operated during the entire day.

"I wish to show by two tables what the cost per kilowatt is both for railway and central-station work in the best



600 H. P. ENGINE DRIVING TWO 200 K. W. GENERATORS.

practice to-day and the general results indicated. The cost of the manufacture of current per kilowatt-hour in a large modern station for lighting, from actual log records, the

plant being triple-condensing, with direct-connected generators, with steam-pressure of 175 pounds, is as follows :

	Cents.	Lbs.
Water, cost	.060	
Coal		4.25
" cost	.515	
Removal of ashes	.026	
Lubrication, waste packing	.022	
Labor, engines, boilers, dynamos, and miscellaneous	.62	
	1.243	
Cost of distributing, including care of overhead and underground lines, house-wiring, lamp renewals, and meters	.767	
	2.010	
General executive expenses, including office expenses, and taxes	1.55	
Total	3.560 cents, or about 1.78d.	

"These results show practically $1\frac{1}{4}$c. (.625d.) per K. W. for manufacture of the current, $\frac{3}{4}$c. (.375d.) for distributing the current, and $1\frac{1}{2}$c. (.75d.) per K. W. for general and executive expenses. This makes the total expenses of the station in question approximately $3\frac{1}{2}$c. (1.75d.) per K.W.-hour. Going further into this, we find that the coal is approximately 40 per cent of the cost of manufacture, labor is 50 per cent of the cost of manufacture, and the total manufacturing cost is 35 per cent of the whole, with the total distributing cost 21 per cent of the whole, and the general and executive expenses 44 per cent of the whole. With increase of business the general and executive expenses show a smaller percentage of the total ratio. Some stations

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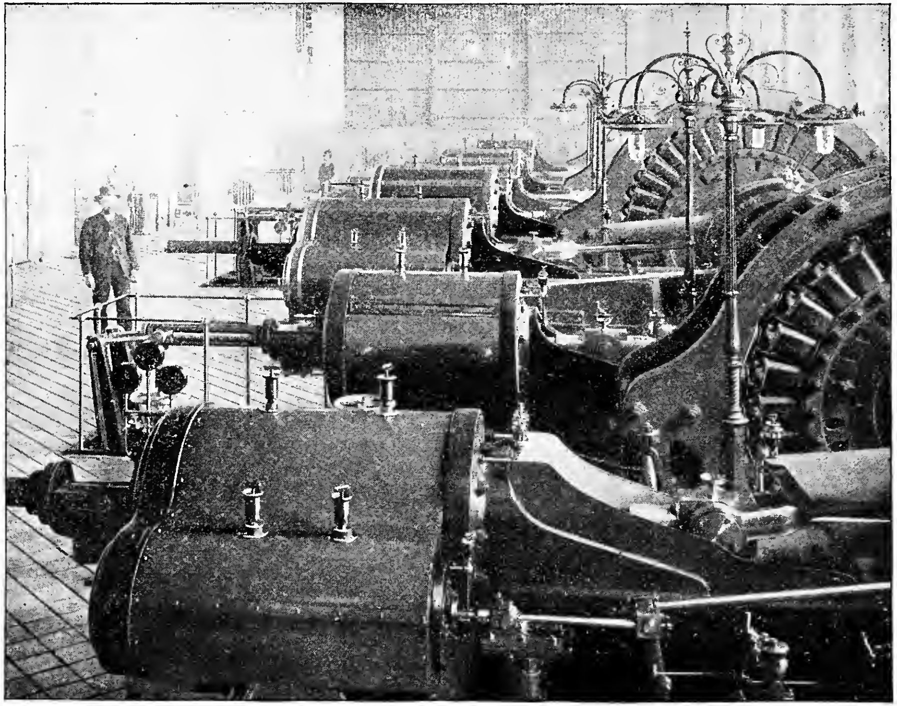
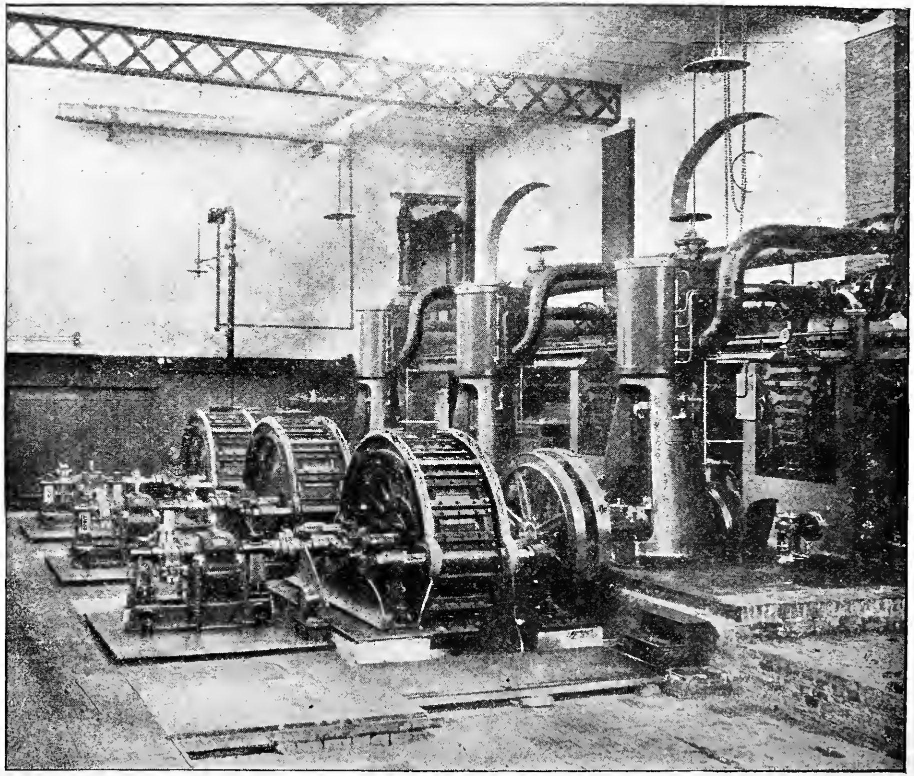


CENTRAL STATION, MILAN, ITALY.

[To face page 301.]



ITALIAN CENTRAL STATION.

show a better average on parts than this one, but I have found none that shows a better average as a whole.

"On railway work, with compound engines and direct-connected units, operating at about 130 pounds steam-pressure, we have the following results:

OPERATING EXPENSES.

Coal at $3.50 (14s.) per ton......	$2,454.50 (£490 18s.)
Labor........................	1,325.00 (£265)
Oil, waste, and repair..........	265.50 (£ 53 8s.)
Total...	$4,045.00 (£809)

"Taking the total number of cars operated and the car-mileage for the month, this being the total expenses for a month, we find that the average cost of power per car-mile is one cent (½d.), the cars being almost entirely 18-foot single-truck cars. The grade conditions and general service are the average. Transferring this cost of car-mileage into cost per K. W. manufactured, determining this cost both from station records and car test of power consumed, we have approximately .9c. (.45d.) per K.W.-hour as the cost of manufacture, in which the coal is approximately 63 per cent of the manufacturing cost, labor 33 per cent, and oil, waste, and repairs 4 per cent.

"I believe we are fast approaching the time when we will show, if we are not already doing it, in some stations, a result in the cost of manufacture per K.W.-hour equal to one cent (½d.) for lighting-stations and ¾c. (.375d.) for railway-stations. The examples indicated here are authentic cases, taken from actual records obtained.

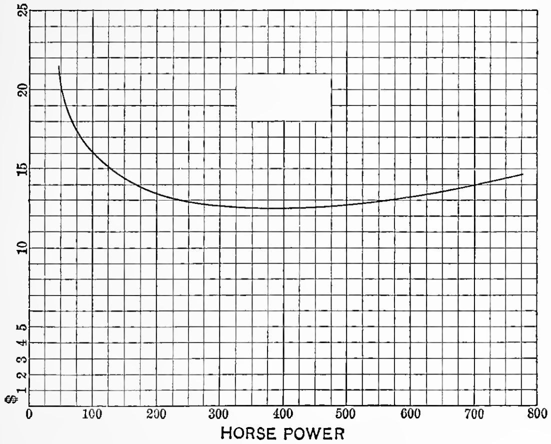
"It may be of further interest to indicate in a general way what such a central power station, say one of 5,000 K. W. capacity, would cost per K. W.: steam-plant, \$85 (£17) per K. W., including engines, boilers, pumps, heaters, condensers, piping, etc.; electric plant, including generators, switchboard, cables, etc., direct-connected units, \$30 (£6) per K. W.; power-station, building under average building conditions of good foundations and no rock excavation, including foundations, building, stack, etc., \$15 (£3) per K. W.; sundries \$10 (£2) per K. W. This makes a total of \$140 (£28) per K. W. This is exclusive of real estate."

In the planning of the steam-engine outfit of large stations the relative cost of large and small units must often be carefully considered. Thus the illustration shows the relative costs of standard engines of an important building firm where, for example, two 300 to 500 I. H. P. engines cost less than a single machine of double power; but the value of the space to be occupied must also be taken into account and the costs of foundation and all running expenses affected by choice of size of unit, as well as the relative desirability of a pair of engines coupled at 90° in the case of cross-compounds.

In the diagram the ordinates measure relative costs, the abscissæ power developed. The curve would undoubtedly differ somewhat with different engines and different shops.

The direction of change is thus well indicated, as well as the present costs of generation of electric energy and its distribution. But it would be folly to attempt to predict what will be the course of improvement in even the immediate future. The whole field is new, and a thousand brilliant

and well-educated professional men in the department of mechanical engineering are working at the thousand of new problems continually presenting themselves, in addition to



the many old ones, and it may be confidently expected that progress will long continue to exhibit itself in peculiarly rapid advances in all directions.

THE COSTS OF DISTRIBUTION OF POWER include, ordinarily, those of overcoming the friction of a large amount of shafting and belting. The magnitude of this cost has been carefully studied by Mr. Henthorn.[1] The power demanded in cotton and woolen mills is rarely much, if any, less than 20 per cent of that furnished by the engine, while it sometimes amounts to 30 per cent and over.

The transmission of steam-power, and the application of energy at a distance from the primary source, with

1. Trans. Am. Soc. M. E , Vol. VI. No. CLXXVII.

economy, safety, and certainty, may often prove a problem of such importance as to justify a careful study and comparison of all available methods. These methods include :

(1) Transmission of energy by carriage of steam to motors distant from the boilers.

(2) Transmission of power from engines set beside the boilers.

In the former case the total power may be supplied, often, either from a single engine or by supplying the steam to a number of smaller engines distributed as may be found best in facilitating work ; and the problem includes that of determining what arrangement and distribution of these engines is, on the whole, most desirable. In the latter case the problem includes the comparison of various methods of transmission of energy from the engines to the work.

The transmission of steam is rarely practised over distances exceeding a few hundred feet at most, although there are no insuperable difficulties, ordinarily, to carrying it thousands of feet, the steam-pipes being well clothed, kept dry, and thoroughly and automatically drained at all low points by traps, separators, or other system. With intermittent service, however, this method is usually found both wasteful and troublesome, especially in meeting the variations of length due changing temperatures, and the "water-hammer" liable to occur when steam is introduced into cold pipes. External drainage of the trenches in which the pipes may be laid is quite as important as the internal drainage of the pipes themselves. Distances approximating a half-mile are thus readily attained. The higher the steam-pressure maintained in the pipes in any given case the less the loss of

pressure by friction, and, usually, the less important any stated drop of pressure.

The engines being placed at the boilers, the transmission of their power to their work may take place by either of several ways:

(1) By shafting and pulleys.
(2) By wire ropes.
(3) By water-pressure in pipes.
(4) By compressed air.
(5) By electric currents.

For short distances, as within workshops as commonly constructed, lines of *shafting* are safest, cheapest, and in all ways best. For driving large isolated and widely distributed machines it is often better to adopt a small engine for each or at each group, supplied with steam from the main boilers, with water or air under pressure from pumps driven by the main engine, or with motors driven by currents supplied from electrodynamic generators similarly driven. The limit for shafting, as an average, may be taken as about 1,000 feet; but the coefficient of friction of shafting, under its light pressures, is very great; the friction is intensified and power wasted by the often inevitable "getting out of line," and the weight is considerable, so that the total waste is apt to be serious. In such cases the engine distributing its power should be as near the center of power utilization as possible.

All pulleys should be carefully balanced and should "run true." All others should be promptly condemned. Tubular shafting has the advantage of stiffness, the disadvantage of large friction. Belting is used under all ordinary condi-

tions ; but it is unfitted either for the transmission of exact velocity-ratios or for slow speeds of rotation and large power.

Where the span is considerable and no shafting is desired, ropes of hemp, cotton, or wire are often employed in place of belts, and 50 H. P. per rope, if hemp or cotton, of 7 inches circumference, at 1,500 feet per minute, is considered good practice. With such ropes arranged "in multiple" great care must be exercised to see that their pulleys are precisely alike in size. Chains may be used instead of belting for very slow and heavy work.

Wire-rope transmission is employed very extensively for long distances, the carrying-pulleys being set at distances of 200 to 500 feet apart, and made of a diameter usually not less than 100 times that of the rope, and preferably 150. It is found that distances of 10 miles or more may be thus attained with a loss not exceeding 25 per cent.

Water-pressure of great intensity, with flow at a moderate rate, often proves a satisfactory system of distribution for moderate distances. An "accumulator" receives the water from the pumps and equalizes the pressure and flow. The incompressibility and fluidity of the liquid especially fit it for such use where the line of transmission is tortuous and irregular. Water taken from the street-mains is often used, under pressures of from 30 to sometimes 100 pounds per square inch. The higher the safe pressure the better, however ; and a special supply at pressures exceeding 300 or even 700 and 1,000 pounds is frequently found best. This system is often adopted for riveting-machines and other portable hydraulic tools and machines. Water-pres-

sure is especially limited to cases in which the power is needed irregularly or at long intervals, when the work consists in the operation of reciprocating motors or machines, when irregular accumulation, as by windmills, is practicable, and where exceptionably great pressures are demanded.

Compressed air is used in cases somewhat similar to the preceding, and has been found especially suitable for mining operations, where water would be liable to freeze, and more particularly when high-speed rotation motors, and machines like rock-drills, are to be driven. It is, however, very wasteful of power, and in large operations it has often been found that no more than 25 per cent efficiency in transmission could be attained, high pressures being employed. This loss is in compression, largely ; the loss by friction in pipes is not so large, and should not exceed 5 per cent per mile. For driving small motors, however, the advantages of air are often great, and it is sometimes extensively used for this purpose. Its value in underground work is often greatest as supplying ventilation in otherwise inaccessible places. Moderate pressures, rarely exceeding 100 pounds, are used. Any form of motor that can be driven by steam may be used with air. For other than power purposes low pressures should be employed.

Electric transmission is finding extensive use in power-distribution, as is perhaps best illustrated by the systems of electric street-railway, and of supplying power for the minor industries. As in lighting, either the continuous current or the alternating may be used, although the former is the more generally adopted ; and the continuous current

may be furnished either by a generator direct or by a storage-battery.

A net efficiency of generator and motor together not less than 75 per cent should be attained. The loss on the line is very uncertain and variable. A tension of about 500 or 600 volts is usual.

The choice of this system is determined by a comparison of total costs. The losses enormously increase as the size of conductor in proportion to power transmitted diminishes. High tensions give great economy in this respect, while increasing leakage. Costs of conductors constitute a heavy tax on the system for long-distance transmission, and 2 to 5 miles may be taken as the ordinary range of practically attainable maxima.

This method has peculiar advantages for street-railway work, and has come into use mainly in that direction. Where lighting-"plants" are already installed, it is often found that the addition of a power system is economical and convenient, as well as otherwise desirable.

The cost of generating power from a fall of 80 feet as reported by Mr. Holt as obtained by dividing the cost of labor and lubricants (interest and depreciation are not included) by the horse-power demanded amounts at present to less than two-thirds of one cent per horse-power per hour, up to 100 horse-power.[1]

The advantages of electrical power for mining operations are :[2]

(1) It can be transmitted over long distances with small

1. Trans. Am. Inst. Min. Engrs, Oct.., 1891.
2. Ibid.

loss, making it possible to use power at such a distance from its source as would render it otherwise unavailable.

(2) The conductors for conveying electrical power require no appreciable space, are easily put in place and repaired, are easily tapped for branch circuits, and form a flexible system throughout.

(3) The electrical system is ideal in its cleanliness.

(4) The stations can be made to occupy a minimum of space.

A good illustration of the flexibility of the system is the diamond drill; in its use the conductors are unwound and strung up as the drill moves along, or taken down and coiled up, as may be found convenient.

The waste of power from friction-resistance in the case of transmission by shafting is usually roughly stated at one per cent per one hundred feet, giving an ultimate limit at about ten thousand feet, or less than two miles, beyond which it is absolutely useless, and making it usually practically undesirable in lengths exceeding a few hundred feet. With electrical distribution this increase of waste with lengthening traverse is much less, and Beringer makes the total cost vary as the third or fourth root of the distance, increasing the more slowly as the power is the greater. Wire-rope transmission has a limit at three or four times that of shafting, or, commonly, five or six miles. Below a maximum of two to three miles this is, at present, the cheapest transmission; for higher figures the electrical is best. Practically the latter would, in most cases, be used beyond a mile.

Beringer has compared the four principal systems of power-

transmission, by water, air, rope, and electricity, and finds the latter usually best.[1] Wire rope is found most economical for short distances, as between 100 feet and a half or three-quarters of a mile, under the conditions assumed; but electricity is preferable beyond that maximum. Hydraulic and pneumatic systems cost much more, although the latter approximates the best figures at high powers and long distances, and all are more nearly alike as power transmitted and distances increase. Where air is wanted for ventilation, as in some mining operations, it often displaces all other methods. Electricity is now finding many applications in mining as well as in other power-transmissions.

It seems probable that these comparisons made with old and familiar systems may be altered somewhat, if not to an important extent, in favor of compressed-air transmission by adopting improved apparatus and methods—for example, as illustrated by the Popp distribution in Paris. By more effective spray-cooling at the point of compression, and by the adoption of a good compound type of compressor, Professor Riedler found it practicable to reduce the wastes from 43 to 12 per cent. By reheating the air at entrance into the engines at the other end of the system Popp obtains, according to Professors Gutermuth and Weyrauch, a transformation of 70 per cent of the heat thus added into useful work, and a net gain of final efficiency of 30 per cent by raising the temperature of the working charge to 250° C. (482° F.). By compounding the motors and reheating between the two in series Riedler reduced the consumption of air from 812 cubic feet per hour per brake horse-

1. Kritische Vergleichung der Electrischen Kraft-übertragung, 1883.

power to 646 with the steam-engine form and with rotary motors from 1,059 to 847; the machines being in both cases of rude construction, inefficient type, and very small size. The investigators of this system consider it possible that it may prove, on the whole, the most economical method of power-transmission.[1]

The losses are always considerable. Thus at St. Fargeau, Paris, air is compressed by the Popp Company to 6 atmospheres, sent 5 kilometers, and operates compressed-air engines at a pressure of 4½ atmospheres and an efficiency of 0.26. Compound compressors, however, may sometimes save a large proportion of the waste heat of compression, raising the efficiency of the compressor from 50 or 60, or from at most 70, to 85 or 90 per cent.[2] Good compressors and good engines should give at least 0.85 for the efficiency of the machine; and compressors should return from 70 to 90 per cent of the work expended upon them. Professor Unwin has computed a transmission for 10,000 H. P. twenty miles through mains 30 to 50 inches diameter, at an initial pressure of 75 to 190 pounds, and velocities of flow of 20 to 50 feet per second, with resultant efficiencies varying from 40 to 50 per cent, or if the air be heated at the engine of 60 to 73 per cent.[3]

The costs and profits per mile run of street-railway power-transmission in Birmingham, G. B., all under a common management, were reported in 1891 as below:[4]

1. London Engineering, 1891; Scientific American Supplement, May 23, 1891.
2. Riedler: Neue Erfahrungen über die Kraft-versorgung von Paris durch Druckluft, Berlin, 1891.
3. Trans. Brit. Inst. C. E., 1891, No. 2548, Vol. CV. Part III. See also Vol. XCIII. p. 421.
4. Engineering, Aug., 1891; Iron Age, Sept. 3, 1891.

	Costs.	Earnings.	Profits.
Steam-plant	21.98	31.34	9.36
Wire cable	12.66	24.06	11.40
Electric	19.80	30.30	10.50
Horse	19.58	22.04	2.46

Running expenses only are included. Interest and repairs should be added. The order given is that of amount of traffic, the steam "cars" doing most work.

It will be usually found that each system is well adapted to a special set of economical conditions, and that neither can satisfactorily replace the other.

Relay power is demanded at times as accessory to the regular and usual motive power, either where streams supply water-power in varying quantity throughout the year, or where the load is itself varying and irregularly applied from day to day or season to season. In such instances steam-power is resorted to at times to supplement the temporary deficiency; and the kind, size, and economical value of the "relay" motor must be carefully considered.

In general, it may be said that if required for a longer time it must usually be more economical than if worked only a short time or for a small portion of the year, as is evident from the considerations studied in connection with problems of commercial efficiency. If used but seldom or for but a brief period, low first cost is the primary consideration; if for long periods, economy of operation must determine the size and character of the engine and its boilers.

Whatever the proportion of time in use, however, the engine should as far as possible conform to the primary requirement:

Minimum total cost of annual operation, including all the items enumerated when considering the problem of maximum commercial efficiency.

To this the following are accessory or subsidiary.

(1) Minimum first cost, consistent with the demanded efficiency.

(2) Efficiency adjusted to meet the primary demand above.

(3) Permanence of efficiency, despite the specially adverse circumstances of its use.

(4) Permanent good condition, though out of use.

(5) Stability of foundations and machinery of transmission.

(6) Minimum trouble and expense in "laying up" and again starting.

(7) Independence of skilled attendance.

The cost of machinery of transmission, whether by belting or gearing, and especially the loss of the power absorbed by its friction, often makes it advisable to avoid its use as far as practicable, and to use separate engines for widely separated machines. This is especially the case in mills and other establishments in which the transmitting machinery constitutes a heavy and continuous load, while the driven machinery is operated only at intervals, and even, as is often the case, at long intervals and for brief periods of time. A judicious distribution of motors in such instances will often effect an enormous annual saving. It must, however, always be considered that, other things equal, several small engines will demand more steam than a single engine of equal total power.

The irregular demand at electric-lighting stations illustrates a peculiar case of what in a sense may also be termed "relay power," and the matter of subdivision of motive power and the problem arising out of it must often be settled by a study of existing "plants" and by reference to earlier experience. The experiments of Dr. Louis Bell being compared with those directly reported to the author indicated a total efficiency of but 25 per cent with large engines and of 37 per cent with small engines directly connected, the work being that of street-railways; but enormous variations are produced by differences in design, construction, and method of operation.[1]

SAFETY DEVICES employed on engines having detachable valve-gearing, when effective, insure against the often disastrous consequences of a "runaway" when the load suddenly drops or is, as sometimes occurs, all thrown off. In this class of engines such sudden removal of load, and the consequent jump of the engine under the steam-supply at the moment before introduced to carry the heavier or the full load, is liable to cause dangerous increase of speed, or even, by slipping the governor-belt or throwing it off, to produce very rapid acceleration up to the speed at which the wheel can no longer withstand the centrifugal forces acting upon it. The consequence has often been the rupture of the fly-wheel and the complete destruction of the engine, with even more serious consequences in loss of life and property by the scattering of parts of the engine with the impetus of a cannon-shot. No engine of this class should be employed where great fluctuations of speed are

1. Electrical World, Aug. 16, 1890, p. 103.

likely to take place, and they are not entirely free from such danger even where, as in cotton-mills, the load is commonly very steady. Accidents of this kind have often happened in electric-light and power stations, especially in the power-stations of electric railways. They have taken place in a number of instances in mills.

The "automatic" engine with its shaft-governor of the Hartnell class is not liable to this particular kind of accident, since any accident to its governor system stops the engine immediately by interrupting the supply of steam.

COSTS.—The following were fair average figures for costs of construction in 1895, but are subject to continual variation with the state of the market :[1]

COST OF STEAM AND ELECTRICAL PLANTS—COST OF ENGINES FOR SIZES OVER 100 H. P.

High-speed, single	$11 to	$13	per	H. P.
" " compound	14 "	16	"	"
Corliss, single	16 "	18	"	"
" compound	22 "	25	"	"
" triple	27 "	30	"	"

COST OF STEAM-PLANTS,

INCLUDING ENGINES, BOILERS, PIPING, PUMPS, HEATERS, FOUNDATIONS, SETTINGS, ETC.

High-speed	$40 to	$50	per	H. P.
Corliss, direct connection	60 "	70	"	"
" counter-shaft	80 "	85	"	"

COST OF ELECTRICAL PLANT.

Dynamos, switchboard, cables, foundations, erecting, etc.	$35 to $40 per H. P.

1. Manual of the Steam Engine. R. H. Thurston (N. Y., J. Wiley & Sons), Vol. II· pp. 887 *et seq.*

Pole-line, including mains, feeders, poles, setting, etc.	4 "	6 "	16 C. P.		
Underground ditto	7 "	9 "	"	"	
Inside wiring, including lamp, socket, plain pendant and rubber-covered wire, moulded work	4 "	5 "	"	"	
Same, for concealed work	5 "	6 "	"	"	

Mr. Field gives the following figures for a case of the purchase, equipment, and operation of a street-railway system with electricity, a city with a population of say 100,000—with a dilapidated street-railway system, earning a gross income of $125,000, to purchase same for $500,000—property rights, franchises, etc., and equip it with 40 miles of single track and 65 electric cars : [1]

COST OF EQUIPMENT.

Steam-plant (1,500 H. P. steam-plant) :

Five engines, 250 H. P. each, compound condensing, size 16 in. × 32 in. × 42 in., with wheels weighing 30,000 lbs.	$32,500	
Eight R. T. boilers, 72 in. × 16 ft.	9,600	
Jet-condensers	3,000	
Two boiler-feed pumps	900	
Steam- and exhaust-piping	12,000	
Five engine-foundations	3,500	
Eight boiler-settings	3,200	
Five 30-in. belts	2,000	
Erecting and starting	3,500	
Freight and miscellaneous	2,500	
		$72,700

1. Trans. Nat. El. Lt. Assoc., Montreal Meeting, 1891.

Electrical plant:		
Five generators, 200 kilowatts	$37,500	
Switchboard installation, foundations, etc.	4,000	
		41,500
Building:		
Power-station, including stack, traveling crane, etc	$25,000	
Car-house and repair-shop, including tools, etc	15,000	
		40,000
Track-construction:		
Forty miles girder-rail construction, ties 2½ ft. centers, 63-lb. rail, etc., $1.15 per foot	$242,880	
Relaying, including paving, etc., at 60 cents per foot	126,720	
Trucking, hauling, etc.	24,000	
Ties, including 10 per cent of joint ties, 130,000 at 40 cents	52,000	
Ties, including 10 per cent of joint ties, 15,000 at 70 cents	10,500	
		456,100
Line-construction:		
Ten miles iron poles, etc	$75,000	
Ten miles wooden poles, etc	40,000	
		115,000
Car-equipment:		
65 electrical equipments at $2,000	$130,000	
65 car-bodies, 18-foot body, with open ends.	65,000	
65 trucks at $250	16,250	
		211,250

Summary :

Steam-plant	$72,700		
Electrical plant	41,500		
Building	40,000		
Track	456,100		
Line-construction	115,000		
Car-equipment	211,250		
		$936,550	
Superintendent's and engineer's work	$50,000		
General and miscellaneous	50,000		
		100,000	
		$1,035,550	
Original purchase		500,000	
Total cost re-equipped			$1,535,550

Gross income, say, $350,000.

The transmission or power over very great distances, as from a waterfall or prime motor to a town or an establishment several miles away, is best effected by the electric current at high tension, as to London from Greenwich by the Ferranti system, or from the Neckar Falls at Dauffen to Frankfort, Germany. The latter is about 110 miles (180 kilometers), and a "pressure" of 25,000 volts is adopted by its designers, the Oerlikon Works, and 300 electrical horse-power is transmitted.

In the organization of such a system of distribution the division of duties is somewhat as follows :[1]

The superintendent is in charge of the station and of all work. If the station is large enough, he may have a man who can attend to the making out of reports. His assistant

1. Trans. Nat. El. Lt. Assoc., 1890.

takes his place at times, and can often decide whether work shall be done, or whether it shall wait for the superintendent's return.

Under the superintendents are the chief engineer, chief dynamo-man, chief lineman, and chief incandescent wireman.

Under the chief dynamo-man are various dynamo-runners, although the chief engineer may be able to take charge of the dynamo-room.

Under the chief engineer are all engineers, foremen, coal-handlers, etc.

In the absence of the chief engineer, the engineer on watch takes his place, and the same with regard to the dynamo-man.

The chief lineman should have under his care pole-lines, outside construction of all kinds, including all arc-lamps and high-tension wires ; also the care of converters, if any, to the first cut-out on the secondary side. He should also have charge of the carbon-setters and arc patrolmen.

The chief wireman should have charge of inside wires, all lamp-renewals, patrolmen, and material and work.

The storekeeper has duties separate from all these.

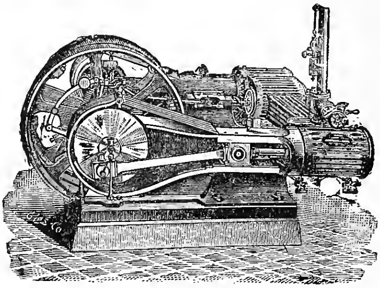
The reports necessary are the engineer's log, for which there should be two books provided,—one for the day run, and one for the night run,—to be filled up by the engineer on watch and turned into the superintendent's office each day for examination.

The dynamo-room log should include a reading of the load on each machine, taken at twenty-minute intervals throughout the whole run. This report, with the amount of coal

burnt, gives a check on the fireman and the quality of coal.

The inspectors and patrolmen should fill out a form, giving the number of arc-lamps on the circuits ; if any are out or burning badly, between what hours, and the probable cause.

The storekeeper should make a report daily of all material received and issued, which can be used as a check upon bills for material.



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